KLAIPĖDA UNIVERSITY

Arūnas BALČIŪNAS

MARINE LITTER POLLUTION AT THE LITHUANIAN OPEN SEA AND COASTAL AREAS

DOCTORAL DISSERTATION

Biomedical sciences, ecology and environmental sciences (03B)

Klaipėda, 2018

Doctoral dissertation was prepared in the period 2013–2017 at Klaipėda University, based on the conferment a doctorate right which was granted for Klaipėda University by the order of the Minister of Education and Science (Republic of Lithuania) No. V-574, signed on 17th July 2017.

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Address: Herkaus Manto 84, LT-92294, Klaipėda, Lithuania.

The doctoral dissertation was sent out on 8th February 2018.

The doctoral dissertation is available for review at the Library of the Klaipėda University.

KLAIPĖDOS UNIVERSITETAS

Arūnas BALČIŪNAS

LIETUVOS BALTIJOS JŪROS IR PAKRANTĖS TARŠA ŠIUKŠLĖMIS

DAKTARO DISERTACIJA

Biomedicinos mokslai, ekologija ir aplinkotyra (03B)

Klaipėda, 2018

Disertacija rengta 2013–2017 metais Klaipėdos universitete pagal suteiktą Klaipėdos universitetui Lietuvos Respublikos švietimo ir mokslo ministro 2017 m. liepos 17 d. įsakymu Nr. V-574 Ekologijos ir aplinkotyros mokslo krypties doktorantūros teisę.

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Daktaro disertacija bus ginama viešame Ekologijos ir aplinkotyros mokslo krypties tarybos posėdyje 2018 m. kovo 9 d. 15 val. Klaipėdos universiteto Aula Magna konferencijų salėje.
Adresas: Herkaus Manto 84, LT-92294, Klaipėda, Lietuva.

Daktaro disertacija išsiųsta 2018 m. vasario 8 d.

Disertaciją galima peržiūrėti Klaipėdos universiteto bibliotekoje.

Abstract

The dissertation provides the findings of the first comprehensive analysis of the marine litter pollution in Lithuania. The amount and distribution of different type of marine litter on the bottom of the sea and at the coast of Lithuania was investigated and the main pollution sources identified. Moreover, the coast exposure to marine litter pollution assessment methodology was developed and applied in order to determine the areas of the Lithuanian coast where marine litter is most likely to accumulate. The study contributes to the national level implementation of the MSFD while defining the level of marine litter pollution and target values in order to achieve a good environmental status in Lithuania and provides practical recommendations for the national marine litter monitoring.

Keywords

The marine litter, artificial polymers, plastic, coast pollution, Baltic Sea.

Reziumė

Šiame tyrime pateikiamos pirmosios išsamios jūrą teršiančių šiukšlių analizės Lietuvoje rezultatai. Darbo metu buvo nustatyti pagrindiniai jūrą teršiančių šiukšlių tipai, kiekiai ir paskirstymas jūros dugne bei Lietuvos pakrantėje, nustatyti pagrindiniai taršos šaltiniai. Be to, darbo metu buvo parengta metodika siekiant įvertinti jūros kranto savybes kaupti šiukšles. Ši metodika buvo sėkmingai panaudota nustatant Lietuvos pakrantės ruožus, kur labiausiai kaupiasi jūrą teršiančios šiukšlės. Tyrimas prisideda prie Jūrų strategijos pagrindų direktyvos įgyvendinimo nacionaliniu lygmeniu. Studijos metu buvo siekiama nustatyti jūrą teršiančių šiukšlių kiekio ribines reikšmes, kurias reiktų pasiekti tam, kad būtų pasiekta gera jūrinės aplinkos būklė Lietuvoje. Be to, darbe pateikiamos praktinės rekomendacijos dėl nacionalinio jūrą teršiančių šiukšlių monitoringo.

Reikšmingi žodžiai

Jūrą teršiančios šiukšlės, dirbtinių polimerų medžiagos, plastikas, kranto tarša, Baltijos jūra.

Contents

1

Introduction

1.1. Relevance of the dissertation

The European Parliament and the Council adopted the Marine Strategy Framework Directive (MSFD) in 2008 (2008/56/EC). The Directive established a framework for community action to mitigate the negative impact on the marine environment. Among 11 descriptors of Good Environmental Status (GES) listed in Annex I of the Directive, descriptor No 10 states, that GES is achieved only when “properties and quantities of marine litter do not cause harm to the coastal and marine environment”. The Commission has provided detailed criteria and methodological standards to help the EU member states implement the MSFD (2017/848/EC), in order to assess the status and monitor the changes in the environment. The concentration of marine litter is one of the parameters that indicate the level of pollution and the general status of the marine environment.

The objective of Descriptor No 10 is embedded in the title “Properties and quantities of marine litter do not cause harm to the coastal and marine environment”. To achieve this, the Commission has identified (by the Decision 2017/848/EC) two primary (D10C1 and D10C2) and two secondary (D10C3 and D10C4) criterions related to Descriptor 10:

Criterion D10C1. The composition, amount, and spatial distribution of litter on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment.

Criterion D10C2. The composition, amount, and spatial distribution of micro-litter on the coastline, in the surface layer of the water column, and in the seabed sediment, are at levels that do not cause harm to the coastal and marine environment.

Criterion D10C3. The amount of litter and micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned.

Criterion D10C4. The number of individuals of each species, which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.

Understanding the characteristics of marine pollutant is a first step in determining the possible threats it may cause to the environment. The marine environment pollution with litter is a result of an increase in production and consumption across all sectors,which generates a vast amount of waste (UNEP and GRID-Arendal, 2016). Artificialpolymer materials (mainly plastics) have become dominant and form from 60 % to 90 % of the marine litter that accumulates on shorelines, the sea surface, and theseafloor (UNEP and GRID-Arendal, 2016). Numerous researches (MARLIN 2013, Gago et al., 2014, Schulz et al., 2015a, Schulz et al., 2015b) were carried out in order to understand the magnitude of anthropogenic pollution with marine litter. The focus of those studies was an estimation of the amounts of marine litter on the beaches. Additionally, studies documenting the facts and scale of events when marine litter is being ingested by marine biota (Boerger et al., 2010, Davison and Asch, 2011, Avery-Gomm et al., 2012) and the possible littering pathways (Nauman et al., 2014) are increasingly abundant. However, the information on the litter sources, the means of release, and the geographical origin, as well as the pathways and the transport mechanisms, are still needed (Veiga et al., 2016). The origin of the litter in the polluted area can be local -directly discarded on the beach or at the sea or can be transported from the inland via rivers, runoff, and prevailing winds.

The determination of trends in the amount, distribution, and composition of micro-particles (Criterion D10C2) is strongly dependent on the selection of sampling methods, which are quite numerous (Hidalgo-Ruz et al., 2012). Moreover, the analysis of micro-particles composition is rather costly (Veiga et al., 2016). Those facts did not allow addressing the D10C2 criterion sufficiently. Therefore, the current study focuses on the analysis of macro-litter washed ashore and/or deposited on the coastline and in the water column (including floating at the surface) and deposited on the seafloor (Criterion D10C1).

The impacts of the litter on the marine life (criterions D10C3 and D10C4) were not analyzed either. The assessment of the scale of ingested litter and later comparison of the results rely on the unified (commonly applied by different countries) methods that have not yet been developed. As no single species can represent the level of ingested litter in different marine areas, a specific range/-es of the species is needed to monitor ingested litter (Veiga et al., 2016).

At the moment, none of the Baltic Sea countries conduct systematic, coast-wide monitoring of marine litter (Veiga et al., 2016). However, new information is being generated during the implementation of European research projects. For example, MARLIN project covered beach litter surveys in 20 key areas in Sweden, Finland, Estonia and Latvia (MARLIN, 2013). Beside international initiatives, national programs developed as well. Beach litter monitoring is being carried out in Sweden, Latvia and Denmark (Keep Sweden Tidy, FEE Latvia). Regional/state monitoring programs are also present in Germany (Mecklenburg-Vorpommern).

The magnitude and the character of marine litter pollution in Lithuania were not studied sufficiently. This study aims to fill the knowledge gaps and provide a holistic overview of the amounts and patterns of accumulation of marine litter as well as possible pressures on the natural and socio-economic environment of the Lithuanian coastal and marine zone. The study aims to develop and apply monitoring methods for GES indicator No 10 assessment in the Lithuanian marine area and coast. The study also focuses on the litter source analysis. This should help in understanding the nature of the pollution and to propose the efficient pollution mitigation measures. The collected materials and applied/adopted methodology will stimulate future research on marine litter. The results achieved will lead to the establishment of sound target values to meet a good environmental status of the Baltic Sea and therefore contribute to the national obligations to the EU and HELCOM as an initial assessment of the current environmental status in the Lithuanian coastal zone and marine areas.

1.2. Objectives and main tasks of the study

The aim of this study was to investigate the level of marine litter pollution in the Lithuanian open sea and coastal areas, identify pathways and sources of pollution and prepare methodological recommendations for monitoring and pollution prevention.

To reach the above-formulated objective, following tasks had to be implemented:

1. The characterization of the marine litter pollution and the identification of sources of pollution in the Lithuanian coastal and marine areas;
2. The comparative analysis of different large micro- and meso-litter sampling methods in order to select the best suitable method for the Lithuanian coast monitoring;
3. The development and application of the coast exposure to marine litter pollution methodological framework in order to determine areas of the Lithuanian coast where marine litter is most likely to be accumulated;
4. The preparation of recommendations for the national monitoring strategy and definition of the target values of national marine litter pollution for achieving the good environmental status of the marine environment in Lithuania.

1.3. Novelty of the study

This study provides the first comprehensive assessment of the marine litter pollution level in Lithuania. The study provides with reliable information on the seafloor and beached marine litter distribution and composition in the Lithuanian coastal and marine areas. The unique methodology to evaluate the coast exposure to marine littering was created and successfully applied. The pollution level based on the analysis of different fractions of litter (macro-, meso- and micro-) along with visual surveys, Frame- and Rake-method were applied for the first time. The dominant pollution sources and most polluted areas of the Lithuanian coast were identified using macro-litter items. The combination of spatio-statistical analysis and coast exposure to marine litter pollution methodology allowed distinguishing most marine litter affected areas in Lithuania.

1.4. Scientific and applied significance of the results

The results of this study are based on the application of the standard methodology formarine litter investigations including litter item material and fraction identification,therefore area applicable for long-term monitoring and also comparison with othermarine regions.

Current study aims to develop and apply the existing methodologies of marine litter investigation. Comparative analysis of those allows evaluate the best suitable methodology for Lithuanian coastal and marine areas. Analyzed spatial distribution of the marine litter on the seafloor provides reliable information on current status of marine litter pollution in the open sea and serves as a base for the future investigations. The results of coast exposure to marine litter pollution evaluation proved to be useful in order to represent areas of increased pollution, important for further coastal management purposes and selection of pollution mitigation measures.

Finally, the results obtained are of a major importance while identifying the national target values for marine litter pollution; are substantial for the implementation of strategic goals of the Marine Strategy Framework Directive and Marine litter action plan (HELCOM, 2015).

1.5. Defensible statements

- The status of marine litter pollution has to be based on meso- and large micro-litter surveys. Due to the high spatial and temporal variability of macro-litter, surveys of the coarser fraction of the litter alone are not sufficient to evaluate the level of marine litter pollution on the sandy coasts of the Southeast Baltic Sea.

- The assessment of coast exposure to marine litter pollution provides a trusted tool to identify the sandy beach areas most likely to accumulate the marine litter.
- The accumulation of marine litter on the Lithuanian coast is determined by the natural hydrodynamic conditions and geometry of the coastline, except areas close to the coastal settlements and/or active touristic locations, where littering is human induced mainly.

1.6. Scientific approval

Results of this study were presented in six international and two national conferences.

International:

The 5th IEEE/OES Baltic 2012 International Symposium "Ocean: Past, Present and Future. Climate Change Research, Ocean Observations Advanced Technologies for Regional Sustainability", Klaipėda, Lithuania, May 2012;

The 9th Baltic Sea Science Congress, Klaipėda, Lithuania, August 2013;

The 12th International Conference Littoral 2014, Klaipėda, Lithuania, September, 2014;

The 10th Baltic Sea Science Congress 2015, Riga, Latvia, June 2015;

The 34th Annual Conference *Geography of Seas and Coasts* (AMK), Warnemünde, Germany, April 2016;

The 11th Baltic Sea Science Congress 2016, Rostock, Germany, June, 2017.

National:

The 7th Scientific-Practical Conference *Marine and coastal researches – 2013*, Klaipėda, Lithuania, April 2013;

The 8th Scientific-Practical Conference *Marine research and technologies – 2014*, Klaipėda, Lithuania, April 2014.

1.7. Papers published

Four publications related to the thesis topic were published:

Balčiūnas A., Blažauskas N., 2014. Scale, origin and spatial distribution of marine litter pollution in the Lithuanian coastal zone of the Baltic Sea. *Baltica*, 27, *Special Issue*, 39-44. Vilnius. ISSN 0067-3064.

Schernewski G., **Balciunas A**., Gräwe D., Gräwe U., Klesse K., Schulz M., Wesnigk S., David Fleet , Haseler M., Nils Möllman N., Werner S., 2017. Beach macro-litter monitoring on southern Baltic beaches: results, experiences and recommendations. *Journal of Coastal Conservation*. ISSN 1400-0350 Printed online: https://doi.org/10.1007/s11852-016-0489-x

Haseler, M., Schernewski, G., **Balciunas, A**., Sabaliauskaite V., 2017. Monitoring methods for large micro- and meso-litter and applications at Baltic beaches. *Journal*

of Coastal Conservation. ISSN 1400-0350. Printed online: https://doi.org/10.1007/s11852-017-0497-5

Schernewski G, Baltranaitė E, Kataržytė M, **Balčiūnas A**, Čerkasova N, Mėžinė J (2017): Establishing new bathing sites at the Curonian Lagoon coast: an ecological-social-economic assessment. *Journal of Coastal Conservation*. DOI: 10.1007/s11852-017-0587-4

1.8. Acknowledgements

First of all I would like to thank my scientific supervisor Nerijus Balžauskas for trust and guidance during my PhD studies. I also thank my scientific advisor Gerald Schernewski for research opportunities and insights in the marine litter field. I deeply appreciate the well-timed encouragements from Sergej Olenin during the PhD studies. I would also like to express my gratitude to Olga Anne and to late Saulius Gulbinskas for encouraging me to apply for a PhD position at Klaipeda University. This work benefited from valuable comments and suggestions from Darius Daunys, Jūratė Lesutienė, Zita R. Gasiūnaitė, Martynas Bučas and Georg Umgiesser.

I am thankful to Kęstas Plauška, Marijus Špėgys and the Fisheries service under the Ministry of Agriculture of the Republic of Lithuania for help in gathering marine litter data on the seafloor. Also, I thank Jovita Mėžinė for deriving prevailing wind parameters for the whole Lithuanian coast.

A very special gratitude goes to Leibniz Institute for Baltic Sea Research Warnemünde and BONUS BaltCoast project for providing a platform for getting experience in scientific community communication and work.

I thank Viačeslav Jurkin for well-appreciated advices and consultations when using GIS software. I express my gratitude to Sergej Suzdalev, Ingrida Bagdanavičiūtė, Miguel Inacio and Donalda Karnauskaitė for all the jokes and side discussions, which helped to look at the topic from the different perspective. Also thanks to all the colleagues from Klaipeda University and Leibniz Institute for Baltic Sea Research Warnemünde for friendly working atmosphere.

I am grateful to my wife for the patience and motivation to move forward during my struggles and doubts. Also, thanks to my family and friends for, sometimes to frequent but well appreciated, expressed care and support during the studies.

1.9. Abbreviations

Abbreviation	Explanation
BITS	Baltic International Trawl Survey
BML	Beached marine litter
GES	Good Environmental Status
HELCOM	Helsinki Commission Baltic Marine Environment Protection Commission
ICES	International Council for the Exploration of the Seas (CIEM)
FT-IR	Fourier Transform Infrared spectroscopy
JRC	European Commission Joint Research Centre
ML	Marine litter
MSFD	Marine Strategy Framework Directive (2008/56/EC)
NATURA 2000	EU wide network of nature protection areas, started in 1992 with EU Habitats Directive
NOAA	National Oceanic and Atmospheric Administration (US)
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
SML	Seafloor marine litter
TSG-ML	Technical Subgroup on Marine Litter under the Marine Strategy Framework Directive
UNEP	United Nations Environment Programme

2

Literature review

2.1. Concept of marine litter

The marine litter, also known as marine debris, is defined as any persistent manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (Galgani et al., 2010; Gall and Thompson, 2015). It includes items made or lost by people, and those deliberately discarded into or unintentionally lost in the marine environment including, among others, items of plastic, wood, metal, glass, rubber, clothing and paper (OSPAR, 2007,Galgani et al., 2010). The material types most commonly found as marine debris: are glass, metal, paper and plastic (OSPAR, 2007), and it is readily apparent from the published literature that on a global scale, plastic items are consistently among the most numerically abundant types of marine debris (OSPAR, 2007; Thompson et al., 2009; UNEP, 2009).

Initially described in the marine environment in the 1960s, the marine litter is nowadays commonly observed across all the oceans (Pham et al., 2014, Peter and Ryan, 2015). The anthropogenic litter on the sea surface, beaches and seafloor has significantly increased over recent decades and is continuously increasing.

The beach litter came under increased scrutiny after Scott (1972) examined the litter found on inaccessible Scottish beaches that have few, if any visitors, and inferred that most litter came from shipping and fisheries operating at the area. Initial studies of beach litter simply assessed standing stocks (Ryan et al., 2009). A high spatial variability of anthropogenic litter amounts has been observed despite unified and standardized monitoring approaches. Hidalgo-Ruz and Thiel (2015) note that marine litter at the coast or at the sea surveys are organised in order to provide information about the temporal and spatial distribution of the marine litter. The accumulation rates vary widely and are influenced by many factors such as the presence of large cities, shoreuse, hydrodynamics and maritime activities (Galgani et al., 2015).

According to the UNEP and GRID-Arendal (2016) marine litter, like other pollutants, affects habitats, ecological function and the health of organisms of the ecosystems where it accumulates. Litter will persist in the sea for years, decades and centuries. However the generalization of marine litter does neglect variety of threats and impacts that different material type or litter items may have in the marine environment. The long persistence of litter (especially plastics) in the marine environment increase the risk of chemical (such as nonylphenols, polybrominated diphenyl ethers, phthalates or bisphenol A) release and absorption of hydrophobic pollutants (including polychlorinated biphenyls (PCBs) and Dichlorodiphenyltrichloroethane (DDT)) (Mato et al., 2001; Teuten et al., 2009). The ingestion of artificial polymer items is recorded for a wide range of organisms, including deposit feeders, filter feeders and scavengers (Thompson et al., 2004). The ingestion of microplastic material presents a route by which chemicals could pass from the plastics into the food chain (Galgani et al., 2013). The plastics themselves also release chemicals as they degrade, increasing the overall chemical burden in the marine environment (UNEP and GRID-Arendal, 2016).

The majority of reported litter-related incidents of the individual marine organisms are related to plastic items. In terms of plastic litter type or use: rope and netting accounted for 57% of encounters, followed by fragments (11%), packaging (10%), other fishing-related litter (8%) and microplastics (6%) (CBD, 2012). Except microplastics all of the previously mentioned marine litter items are among the most common items on the Lithuanian coast.

The marine litter size and the animal groups affected by entanglement, suffocation and/or ingestion is well described by GESAMP (2015). The range starts from the invertebrates and other filter feeders (litter fraction from < 1 μm) up to largest marine organisms (whales, seals, birds, etc.). The trends related to the amounts of fragmented marine litter items (plastic/polystyrene pieces between 2.5 cm and 50 cm in diameter) could serve as an indicator for possible threat of ingestion by marine organisms. This size category according to the GESAMP (2015) study would potentially cause harm to animal groups ranging from fish, birds to seals and whales.

Scarce information regarding the sources of litter, transportation to and movement in the marine system, as well as other general information on characteristic of litter in the marine environment is the main obstacles in developing effective measures for mitigation of an issue. This type of knowledge regarding the marine litter is necessary for the national and regional level risk that litter pollution may cause to environment, assessment. The wide range of attempts on describing litter situation in marine environments has been made globally. The most common approach for assessing pressure caused by the litter on the marine environment has been monitoring amounts of beached marine litter (MARLIN 2013).

2.1.1 The dominance of plastics

Plastic is a diverse group of synthetic polymers that have been known since the late 19th century and were widely spread in the mid-twentieth century. The low density, durability, and relatively low cost make plastic to be an ideal material for a wide range of manufacturing and packaging applications. Since mid-20th century up to date plastics should be considered as hazardous materials (Rochman et al., 2013). The Sea is the place where plastics tend to accumulate (Barnes et al., 2009; Ryan et al. 2009) and pose most of the threats (Gregory 2009; Thompson et al., 2009), where waste is found.

Although, decreasing amount of observed macro-litter (>2.5 cm) on the beaches of remote islands suggest that regulations to reduce dumping at the sea was successful (Eriksson et al., 2013), both the demand and the production of plastics reached 322 million tons in 2015 and is increasing (Fig. 1).

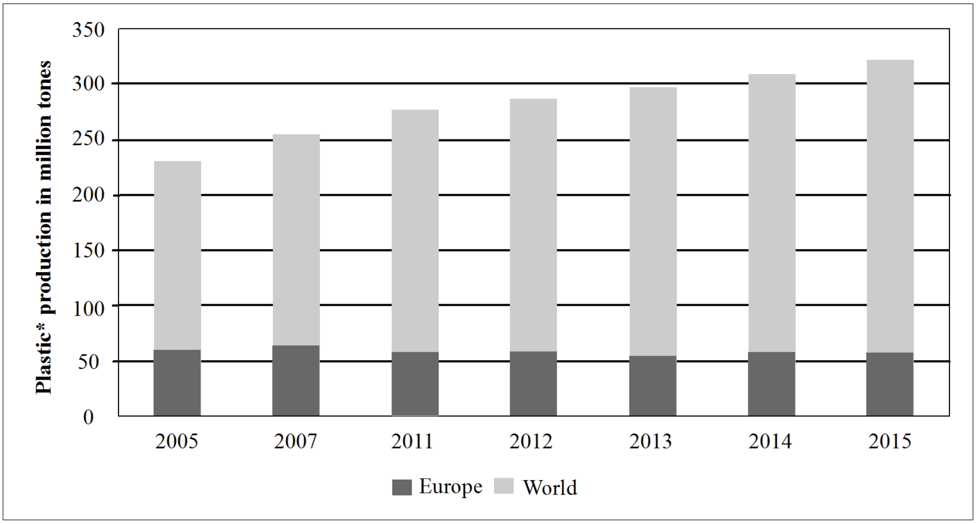

Figure 1. World and Europe plastic production data.*Includes plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings and sealants). Does not include the following fibres: PET-, PA-, PP- and polyacrylic-fibres. (PaslticsEurope, 2016)

1 pav. Kasmet pagaminamo plastiko kiekis pasaulio bei Europos rinkoms. *Pateikti duomenys apima sintetinius polimerus (termoplastikus ir poliuretanus) bei kitus plastikus. Duomenys neapima šių sintetinių pluoštų: PET-, PA-, PP- ir poliakrilinio pluošto. (PaslticsEurope, 2016).

Nowadays plastic is the most often met type of marine litter and sometimes counts up to 95 % of total items found. According to the observations made by Topçu et al. (2013) and Thiel et al. (2013) plastics are found everywhere in the marine environment. Moreover, the plastic items, such as bags, fishing equipment, food and beverage containers contribute to more than 80 % of litter stranded on the beaches. This phenomenon can also be observed on the seafloor where 90 % of litter caught in the benthic trawls is plastic (Galil et al., 1995; Galgani et al., 1995, 2000; Ramirez-Llodra et al., 2013). Due to the long degradation time and based on the publication presented by Song et al. (2009) arguably non-biodegradable plastics pose a long-lasting threat to the marine environment.

A large variety of plastics are produced worldwide, but 6 classes dominate the market, those are: polyethylene (PE, high and low density), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including expanded EPS), polyurethane (PUR) and polyethylene terephthalate (PET) (Andrady and Neal, 2009, GESAMP, 2015). Thermoplastics: PE, PP, PS, PVC and PET, are the main composition material for plastic bottles, food containers, textiles, fishing gear, bags, cigarette butts (GESAMP, 2015). The thermoset polymers (PUR, epoxy, alkyd, etc.) are used for manufacturing balloons, insulation, coatings, tires, adhesives. The microplastics are either manufactured (primary), as a micro-sized raw material for moulding of the thermoplastic and the thermoset products or the result of fragmentation (secondary) of the macro-plastic litter.

2.1.2 From macro- to micro- litter

The gradual fragmentation of larger pieces of marine litter due to the weathering on the land or the sea results in a secondary microplastics production (Thompson et al., 2004;Ryan et al., 2009 and Cole et al., 2011). The ultraviolet (UV) radiation, as well as the oxidation and the physical abrasion cause fragmentation of larger litter items (Browne et al., 2007; Rios et al., 2007; Moore, 2008;Andrady, 2011). According to the size of items, marine litter is divided into categories: mega- (> 1 m), macro- (from 1 m to 2.5 cm), meso- (from 2.5 cm to 5 mm), micro- (< 5 mm).

However, the size limits, for micro- litter category may differ (UNEP GRID, 2016; MSFD TG ML 2015). The upper limit of the size interval bound widely (but not exclusively) accepted. In 2013 MSFD technical subgroup on the marine litter has suggested that the litter of <5mm in their largest dimension is associated to the micro litter. The lower limit of the micro litter size is not clearly stated in the definition, therefore, usually, it is determined by the sampling (the mesh size of a net or a sieve) or the analytical equipment capabilities (filters used in sample purification).

Today, the microplastics recorded to be widely dispersed in the environment and are present in the water column, on the beaches and on the seabed (Barnes et al., 2009;

LaW et al., 2010; Browne et al., 2011; Claessens et al., 2011; Collignon et al., 2012; Peng et al., 2017). Relatively recent research by Barnes et al. (2009) have indicated that meso- particles (5–25 mm) and micro-particles (<5 mm), have become more numerous and as floating litter items can be transported over long distances by prevailing winds and currents. The smallest particles of the marine litter earlier described by Colton et. al. (1974) and Thompson et al. (2004), who used more advanced sample analysis equipment (FT-IR spectroscope) to describe the microplastic fibre fragments (~ 20 µm diameter).

In this study, we use 2mm as a lower limit of the micro-litter.

2.2. Sources of marine litter

Just as the human activities are varied and widespread, so are the sources of litter (UNEP GRID, 2015). The sources may be located directly in the sea, on the coast or further inland. Due to the natural forces and watercourses, litter to the marine environment may be transported from long distances.

According to Mark A. Browne (2015) the sources of litter can be either land-based or ocean-based. The pollution sources can also be economic activity attributed: fishing, sewage system, tourism etc. When use/economic sector related, litter reduction measures are easier to propose (Galgani et al. 2011).

Litter associated with the recreational activities at the coast is the mainland-based pollution source. Litter may reach marine environment via rivers (Rech et al., 2014; Sadri and Thompson 2014) or blown by the winds from a waste management centre or a landfill installation near the river or the sea.

Napper et al. (2015) indicated that micro-plastics used in cosmetics and cleaning agents may enter the marine environment by sewage discharge. The industrial processes where microplastics particles are used as abrasives can be a marine environment pollution source. A common household can be a source of microplastics, since synthetic fibres from the textiles are released into the sewage system during washing (Browne et al., 2011). Because of their size, the concern is that microplastics will not be effectively removed by the sewage treatment and will thus enter aquatic environments. An improper treatment of the sewage sludge (disposal on land or at sea) may be a cause of the marine environment pollution with already subsided particles (Zubris and Richards, 2005).

Litter is introduced into the marine environment, mainly, via improper disposal in the toilet, illegal dumping, inadequate waste management or loss of gear (Veiga et al., 2016). The pathway of litter entering marine environment may start at the recreational or fishing boats, aquaculture, shipping, beachgoers or harbours and ports. In addition, litter to the marine environment may be transported via sewage system, run-off and river flow, wind or prevailing water currents. Therefore, patterns of the sea currents, tidal processes, distance to the urbanised areas, shipping lanes and fishing grounds influences quantities and composition of the litter in the marine environment.

The ocean-based sources of marine litter are associated with the commercial and the recreational activities in the sea. Such activities include shipping (commercial liners, ferries, recreational vessels, etc.), also wind energy installations, parks oil rigs and aquaculture sites.

The geographical distribution of marine plastic debris is strongly influenced by the entry points and the different transport pathways, which are in turn determined by the density of plastic debris coupled with the prevailing currents, the wind and the waves (Rech et al., 2014). In order to trace and document the global trends of the floating plastic debris, transportation and accumulation oceanographic numerical models are being used (Cózar et al., 2014, Eriksen et al., 2014).

The marine litter research is shifting from macro- to micro- particles. Earlier, an investigation of the beach pollution was dominating. Nowadays the marine litter related studies more often use particle or a concentration pathway modelling (Maximenko et al., 2012, Cózar et al., 2014, Eriksen et al., 2014). These studies aimed at the development of models for predicting the behaviour of the marine litter. The models should enable us to grasp the actual conditions of drift and beaching of floating marine litter in the marine environment and enable us to identify the source regions (Balas et al., 2004, Yoon et al., 2010).

However the coastline exposure to marine litter pollution is usually neglected. Therefore, a part of analysis of the current status of the marine litter pollution in the Lithuania, this study introduces the concept of a coastline exposure to marine litter pollution.

3

Material and methods

3.1. Survey area

3.1.1 Lithuanian marine area

The Lithuanian marine area (LMA) refers to the entire Exclusive Economic Zone (EEZ) and the Territorial waters (TW) of the Republic of Lithuania which is located in the South-Eastern part of the Baltic Sea. It borders with the marine areas of Latvia in the North, Russian Federation (Kaliningrad oblast) in the South and Sweden in the West. The area of the LMA is around 6,427 km^2. This relatively small area accommodates the multipurpose, universal, deep-water port of Klaipėda, the recreational port in Šventoji, the UNESCO World Heritage site in the Curonian Spit, the oil terminals in Būtingė and Klaipėda and the offshore military polygons. Recently, certain areas reserved for the offshore wind energy developments and the sand extraction purposes.

Big part of the LMA (Territorial waters and Exclusive Economic Zone) belongs to the Klaipėda-Ventspilis plateau, the northern slopes of the Gdansk Basin and the small part of the northern part of the Gdansk Basin. There are three comparatively deep areas in the Lithuanian EEZ and those are related to the main depressions – the Gdansk and the Gotland basins and the palaeovalley of Nemunas River. The water depths in the Gdansk Basin are more than 80, in the Nemunas River palaeovalley – more than 70 and in the Gotland Basin – more than 100 meters. The central part of the LMA is rather flat, determined by the south-westerly inclined slopes of the Gdansk Basin. The maximum depth of the LMA is recorded at the slope of the Gotland Basin where it reaches 125 m, while an average depth is approximately 50 m.

Wind is the main driving force for the wave regime in the Lithuanian EEZ. The highest waves are observed in autumn-winter period; the smallest – in summer. The wave direction is also corresponding to the prevailing wind direction during mentioned seasons. The highest waves are generated by the westerly winds. The maximum height (9.8-10.6 m) of the waves is observed in the northern part of the Lithuanian near shore (in front of the Šventoji settlement), at the 15-20 m water depths (based on LEI, 2005).

The knowledge on the prevailing currents is mainly focused to the near shore zone, where currents induced by the changing wind conditions are observed. Those (wind induced currents) in fact are of the highest velocity (can reach up to 0.50 cm/s during the storm events). The strongest currents can reach up to 150 cm/s, but in general, mean current velocity does not exceed 10 m/s (~65 % of all recorded currents). Along the shore, the current direction is also determined by the wind direction: north oriented currents are induced by the W, SW, S and SE winds; south oriented currents are a result of the N, NW, E and NE winds.

The vertical distribution of the temperature is season dependent. The water is cold and homogeneous from December through March due to the intensive convection. In summer, the thermocline is formed at 20-30 m depths, which separates water layers of upper warm and relatively cold deep water. The temperature gradient between near-bottom waters in the coastal and the offshore areas can reach 12-15 °C (Jūrinių tyrimų konsorciumas, 2012).

The nearshore slope, extending from the shore down to 25-30 m, is characterised by the most diverse bottom types. The uppermost part (0-6 m), is covered by a thin layer of quartz sand, movable during storms (Gelumbauskaitė, 2000, Žaromskis ir Gulbinskas,2010). The morainic bench (pebble-gravel deposits with large boulders) lies beneath the sand layer, extending down to 25-30 m depth (Gelumbauskaitė et al., 1999). The patches of pebble/gravel deposits occur on the sites down to 60 m, but in general, this type of bottom is common only for the coastal slope. The soft bottoms change from the mixture of sand and gravel in the coastal area affected by the waves to aleurites and pelitic muds in the deeper areas. In general, coarse and medium sands occur from the shore down to 20-40 m depth, and fine sands – down to 50 m. Patches of coarse aleurites are already found at 20-40 m, they extend down to 70-90 m depth. The fine aleurite and aleurite-pelitic mud encircle the slopes of the Eastern Gotland Basin at depths between 80 and 100 m, and finally, below 90-100 m the main type of bottom sediment is a pelitic mud, which covers the slopes and floor of the Basin (Jūrinių tyrimų konsorciumas, 2012, Gelumbauskaitė et al., 1999).

The Lithuanian marine coast is very exposed to any western winds with the fetch distance over 400 km. Therefore, the coastal area is an active hydrodynamic environment.

3.1.2 Characteristics of the beaches

The Lithuanian Baltic Sea coast is west oriented and is only 90.6 km long (Bitinas et al., 2005, Bagdanavičiūtė et al., 2012). The coast is divided into two sections: The Curonian Spit and the mainland coast separated by the Klaipeda straight connecting the Curonian Lagoon and the Baltic Sea (Fig. 2).

Beaches are among the most dynamic environments in terms of physical processes. The shape and position of the beach as well as the protective dune features directly respond to any change in the hydrodynamic and meteorological conditions of the area (Jarmalavičius et al., 2011). The coast and the beaches are very much open to the waves and the eolic processes (Kriaučiūnienė, et al., 2006, Žaromskis. et al., 2008, Žaromskis, et al., 2010). Often, during the storm, beach morphometric indicators may change in hours. Therefore, observed beach dynamics analysis may differ depending on the time period of observation short-term representing one or several storm period or long-term representing seasonal or annual periods.

The mainland coast is characterized by interchanging segments of the accumulative and abrasive coast. 3.5-4 km north from the Klaipeda straight entrance channel there is the single cliff with rocky coastline observed (Žilinskas et al., 2001). Such conditions are also reflected in the changing width of the beaches. The widest beach is south to the Sventoji harbour pier and the narrowest is north to the Klaipeda harbour pier. Due to the coastal erosion, the beaches at the main resort area – the Palanga beaches started to retreat (width became less than 20 meters in some places), and measures to sustain the resort capacities had to be applied. Therefore, during the period of 2008-2012 the Palanga beaches were nourished by sand and width of the beach increased to approximately 70 meters, compared to 14-20 meters before nourishment. Usually, beaches of the Curonian Spit are much wider. In the Curonian Spit almost 47 % of the beaches are 40-60 meters wide while north of the Klaipeda straight only 20 % beaches have the same width (Žilinskas et al., 2001).

Ten beaches representing different nature and human pressures analysed in the current study (Figure 2 and Table 1).

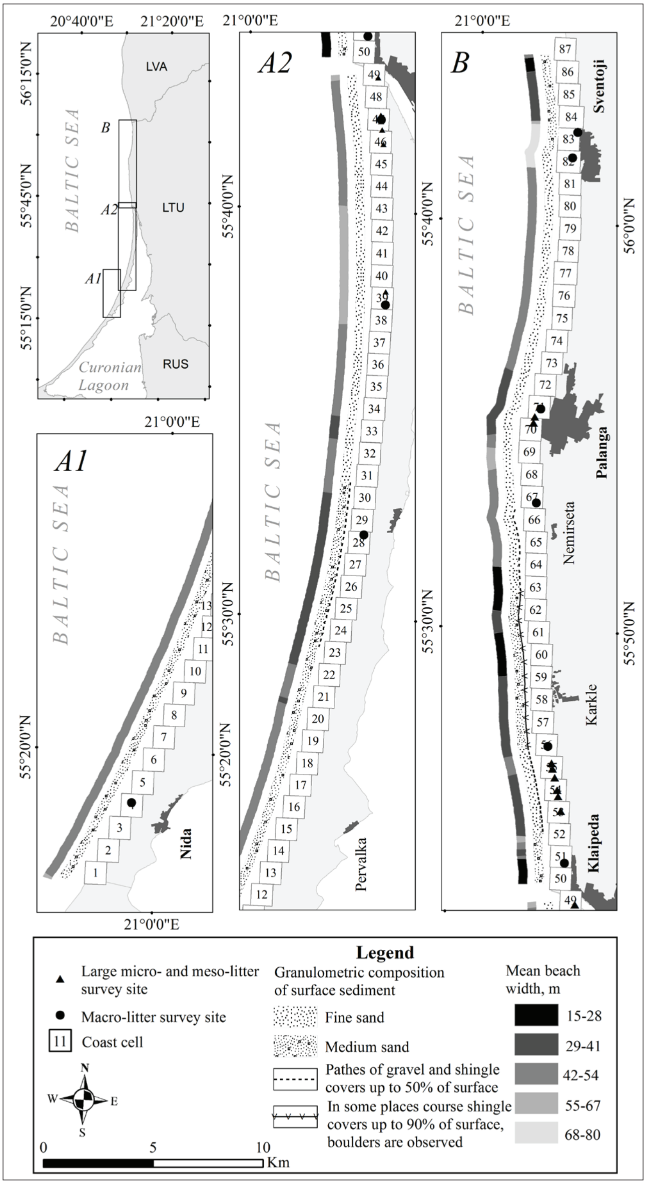

Figure 2. Distribution of the beached marine litter survey sites in Lithuanian Baltic Sea coast (A –Curonian Spit, B – mainland coast). Grain-size distribution of the beach surface sediment acquired after Žilinskas et al. (2001) and the beach width acquired after Žilinskas et al. (2001), Jarmalavicius et al. (2010), Gulbinskas (2014)

2 pav. Paplūdimius teršiančių šiukšlių stebėjimų vietos Lietuvos Baltijos jūros pakrantėje (A- Kuršių nerija, B – Žemyninis krantas). Paplūdimio paviršinių sąnašų granuliometrinė sudėtis nustatyta pagal Žilinskas ir kt. (2001) bei paplūdimio plotis nustatytas pagal Žilinskas ir kt. (2001), D. Jarmalavicius ir kt. (2010), S. Gulbinskas (2014)

Table 1. **Spatial and granulometric characteristics of the beaches of macro-litter survey.**

1 lentelė. **Paplūdimių, kuriuose stebėtos makrošiukšlės, erdvinės ir paviršiaus nuosėdų granuliometrinės charakteristikos.**

Name of the beach	Coordinates of the transect centre, LKS TM 94		Mean area of the beach, m^2	Mean width of the beach, m	Grane-size composition of surface sediment*	Beach type**
	Longitude	Latitude				
Nida	308450.458283	6134922.723180	6909	55	Medium sand, shingle covers up to 20% of surface	Touristic
Juodkrante	316800.766374	6159331.819310	3886	34	Medium sand, Patches of gravel and pebble covers up to 50% of surface	Touristic
Nordbalt	317783.022222	6169811.657030	7191	68	Fine sand	Wild/ Rural
Smiltyne	317595.289198	6178247.330430	6770	61	Fine sand, solitary fractions of gravel	Touristic
Klaipeda	316984.249017	6182059.366830	5873	50	Medium sand, solitary fractions of gravel	Urban/ Touristic
Karkle	316227.553343	6187387.708640	3179	31	Medium sand, in some places course gravel covers up to 90% of surface, boulders are observed	Peri-urban
Nemirseta	315702.920043	6198483.734030	4227	48	Fine sand, solitary fractions of gravel	Peri-urban
Palanga	315907.724396	6202769.526260	7369	39	Fine sand, solitary fractions of gravel	Urban/ Touristic
Sventoji S (South)	317359.692867	6214209.331910	8709	77	Fine sand	Touristic

Name of the beach	Coordinates of the transect centre, LKS TM 94		Mean area of the beach, m^2	Mean width of the beach, m	Grane-size composition of surface sediment*	Beach type**
	Longitude	Latitude				
Sven-toji N (North)	317590.891188	6215371.525230	4795	42	Medium sand, gravel covers up to 20% of surface	Touris-tic

*- Grain-size distribution and beach width acquired after Žilinskas et al., 2001; Jarmalavicius et al., 2010 and Gulbinskas 2014/Paviršiaus nuosėdų granuliometrinė sudėtis ir paplūdimio plotis nustatytas pagal Žilinskas ir kt., 2001; Jarmalavicius ir kt., 2010 ir Gulbinskas 2014

**- Beach typology acquired based on the spatial planning documents, relevant protected area maintenance plans and National Reference Base Data Set (GDR10LT) / Paplūdimių tipologija paremta erdviniais planavimo dokumentais, gretimybėje esamų saugomų teritorijų tvarkymo planais ir Nacionaline georeferencinių duomenų baze (GDR10LT).

3.2. Field survey

The marine litter from the beach and also marine areas was collected during the beach and open sea campaigns in 2012-2016. Collection of the study material was based on the already existing monitoring methodology. At the same time, new approaches for monitoring of marine litter in different marine environments (seafloor and coast) was developed and tested.

The beached marine litter surveys can be divided into three categories: macro-litter survey, meso- and large micro-litter survey, georeferencing survey.

3.2.1. Sampling of macro-litter

86 macro-litter surveys were performed on 10 Lithuanian beaches in order to assess the marine litter pollution of the coast. Each survey site was monitored at least four consecutive times (representing each season) during the period of 2012-2016 (Table 5). The sampling methodology followed guidelines and protocols provided by the OSPAR Commission (2010). The data were collected from fixed 100 m long beach segments covering the entire width of the beach (between seafront and up to the protective dune slope). The position of each 100m segment was GPS georeferenced. All visible items found at the sampling area were identified and entered into the standardized survey protocols. The surveys were performed by minimum two surveyors. However, when possible, a group of volunteers/students were involved in the surveys. In order to properly identify and classify the found litter items, the specific OSPAR photo guide was used.

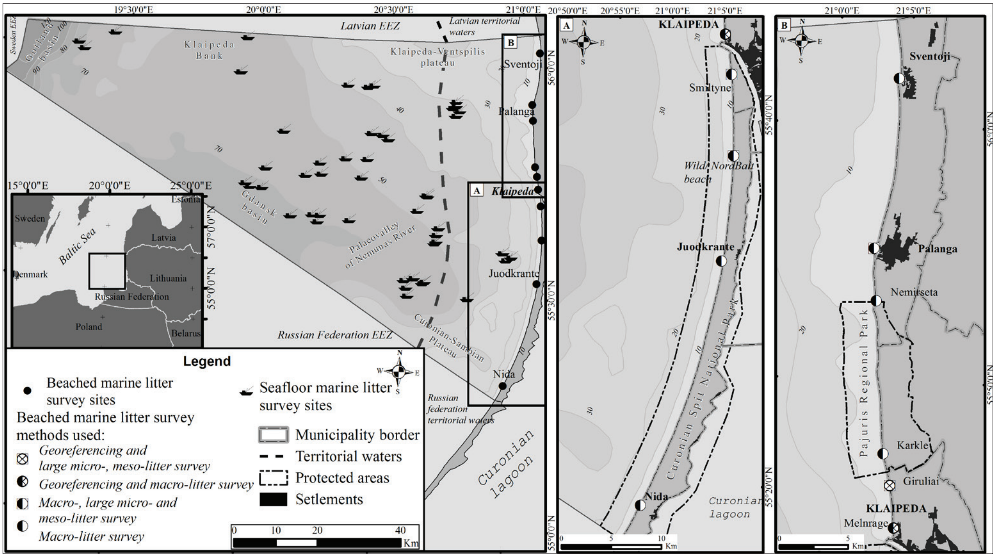

Figure 3. Litter collection sites: A - Curonian Spit; B – Mainland coast

3 pav. Jūrą teršiančių šiukšlių tyrimų vietos: A - Kuršių nerija; B – žemyninis krantas

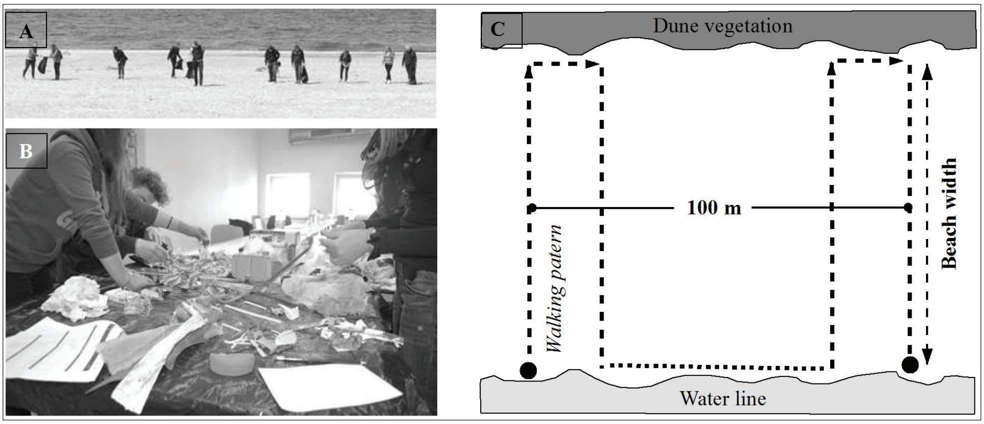

Figure 4. Macro-litter survey. A – collection of the beached litter, B- sorting of collected litter according to OSPAR Commission (2010) forms, C- macro-litter observation and sampling scheme.

4 pav. Makrošiukšlių tyrimas. A –paplūdimį teršiančias šiukšlių rinkimas, B – surinktų šiukšlių rūšiavimas, Pagal OSPAR (2010) gaires, C- makrošiukšlių stebėjimo ir surinkimo schema.

3.2.2 Sampling of meso- and large micro-litter

Sampling of the beach surface for meso- (from 25 to 5 mm) and large micro- (from 5 to 2 mm diameter) litter was carried out in 5 beaches of the Lithuanian coast (Fig. 3). The survey sites were selected based on the existing macro-litter surveying experience and initially focused on the touristic, urban beaches. A total of 25 surveys for meso- and large micro-litter were carried out during the period of 2014-2016. The data were collected according to two methods (Frame (N=14) and Rake (N=11)) described by Haseler et al. (2016), using metal sieves of 2 mm mesh size.

Following the Frame-method entire width of the beach was divided into three equal parts: upper beach, middle beach and lower beach. Each part of the beach was represented by a 1 m^2 sampling area (Fig. 5F). The lateral distance between square meter sampling areas was 20 m. The sampling area was flattened before scooping the sand from the surface with a metal spatula. The superficial layer of sand (tom 3 cm) was placed in a metal sieve, carefully dipped (noting not to overflow) in a bucket with half full sea water and shaken. The process was repeated until all sampling area surveyed. All the litter particles left after sieving in the water were placed in a plastic bag with a survey label.

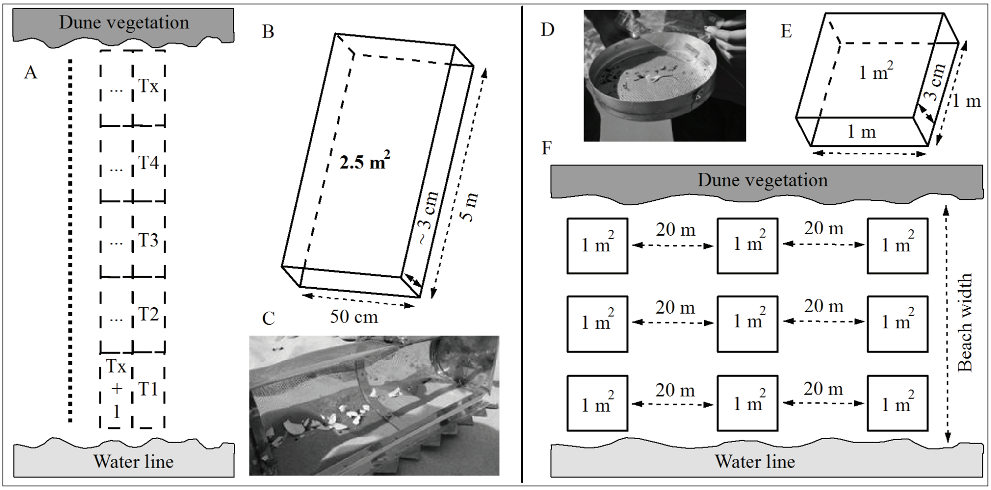

Figure 5. Meso- and large micro-litter survey. Sampling schemes for Rake- (A) and Frame-method (F), explication of single survey area for Rake- (B) and Frame-method (E), Pictures of items left after sand sieving (C, D).

5 pav. Mezo- ir mikrošiukšlių tyrimas. Stebėjimas ir surinkimas pagal Rake (A) ir Frame metodą (F). Vieno stebėjimo laukelio eksplikacija pagal Rake (B) ir Frame (E) metodą, bei šiukšlės likusios po smėlio sijojimo (C,D).

Following the Rake-method an entire width of the beach (from the waterline and until the vegetation and/or cliff) was covered. The beach was divided into 5 m long and 0.5 m wide segments-transects (starting at the waterline) using marker-flags (Fig. 5 A). Depending on the beach width this led to a different number of transects on one cross section of the beach. Due to the varying width of the beach the last transect (at the vegetation and/or cliff) was most often shorter than the rest. Sampling started in a stripe 1 in transect 1 (T1) followed by T2, T3 and so on (minimum number of investigated transects is 20). Each transect was 2.5 m^2 (Fig. 5 B).

The superficial layer of approximately 3 cm of each transect was rake scooped and manually sieved out. Found litter items were inspected in detail visually, placed in a plastic bag and numbered accordingly. The minimum area to be sampled per 1 survey was 50 m^2. If one stripe of transects covering the entire beach width was not reached, parallel transects were sampled until the minimum required area was reached (Fig. 5 A).

3.2.3 Macro-litter spatial distribution

One of the specific tasks of the study was to investigate the spatial peculiarities (abundance, distribution and the concentration) of the different type of litter. Three intensively utilized beaches were pre-selected for this type of exercise: Melnrage I, Melnrage II and Giruliai.

First, the digital survey protocol (Geodatabase) was created using ArcMap software. The geodatabase was based on the 20 macro-litter types most common for the Lithuanian beaches. The National Reference Base Data Set GDR10LT and the orthophotographic images were used as a base map for the ArcGIS database/map. Created digital survey form and the base maps of three selected beaches were uploaded to the online ArcGIS platform.

Fieldwork followed guidelines provided by the OSPAR Commission (2010). Two neighbouring 100 m beach transects were surveyed using a mobile device, connected to the pre-prepared survey files on an ArcGIS online platform. The geographic coordinates were recorded for each of the macro-litter item. The collected data allowed for a spatial analysis of macro-litter distribution and density (Fig. 6).

3.2.4 Litter on the seafloor

The sampling of the seafloor litter was made in the collaboration with Fisheries Service under the Ministry of Agriculture of the Republic of Lithuania. The data were collected during 49 Baltic International Trawl Surveys (BITS) campaigns (Fig. 7) during the period of 2012-2016. The TV-3#520 bottom trawl was used during the surveys. The duration of standard haul was 30 minutes with towing speed of 3 knots. The start time of survey was the moment when the vertical net opening was stable

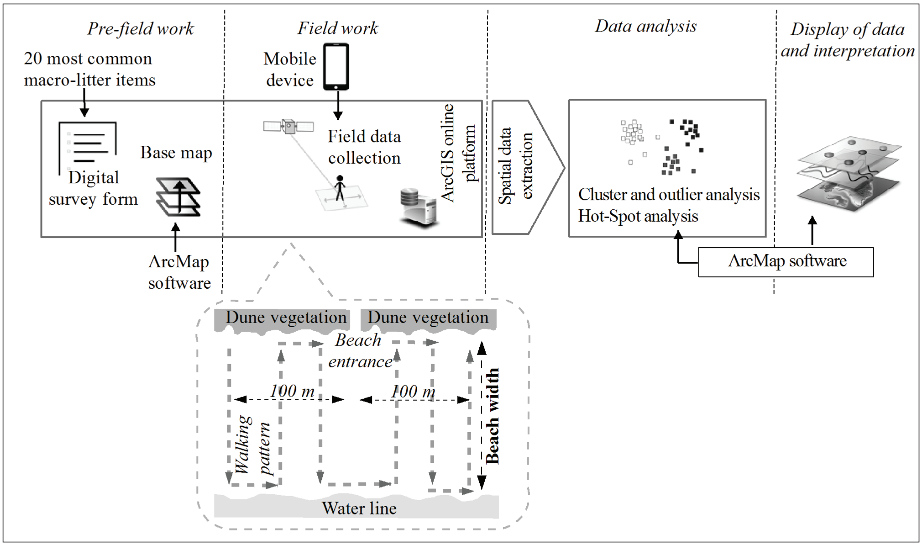

Figure 6. Scheme of macro-litter georeferencing.

6 pav. Makrošiukšlių stebėjimų geografinės nuorodos sudarymas.

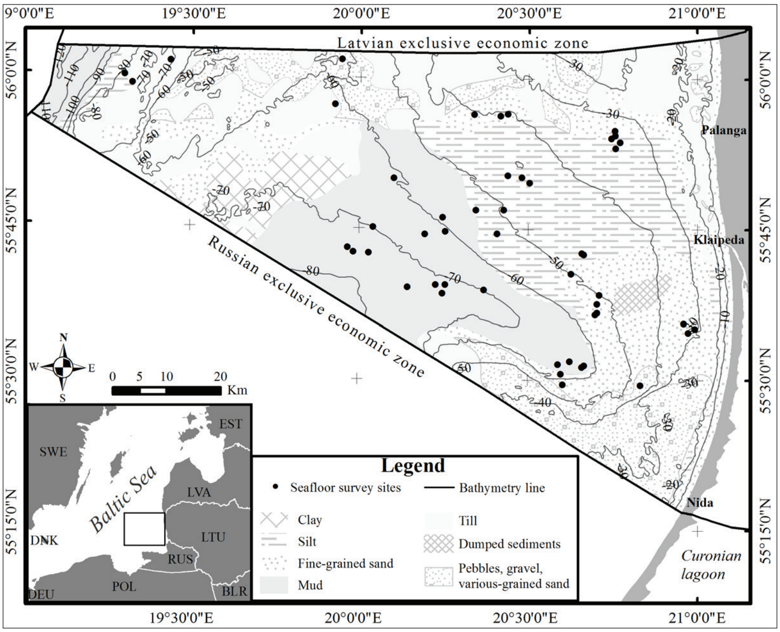

Figure 7. Distribution of the seafloor survey sites in Lithuanian marine area (bathymetry acquired after Gelumbauskaitė, L.Ž., 2009)

7 pav. Jūros dugną teršiančių šiukšlių tyrimų vietos (batimetrija pagal Gelumbauskaitė, L.Ž., 2009).

at the required towing speed and the gear had bottom contact. The depth of the bottom surveys varied from 21meters in the Curonian-Sambian Plateau to 77 meters in the slope of Gotland basin. All seafloor marine litter items were counted and categorised according to the International Council for the Exploration of the Sea (ICES) codes (ICES, 2012).

3.3. Coast Exposure to marine litter pollution

The coast exposure to marine litter pollution analysis was performed using an ArcMap software. The parameters used for the analysis were:

- **Urbanization level, Accessibility, Indirect pollution** and **Distance to harbour** – derived from the National Reference Base Data Set GDR10LT and the orthophotographic images;
- **Distance to the frequently used shipping routes** - based on HELCOM vessel Automatic Identification System (AIS) database of monthly average maritime traffic statistics for the periods of 2008 and 2011, where minimum monthly AIS density (monthly average) was above 30 ships;
- **Attendance level** derived from geotag data using the Google Earth's Panoramio picture layer (Depellegrin et al., 2014);
- **Prevailing wind**, the wind field data were obtained by a numerical weather forecast from the European Centre for Medium-Range Weather Forecasts (ECMWF). The prevailing wind data were derived as mean wind direction for wind speed above 8 m/s for a period of 2012-2016;
- **The Prevailing surface current** for each cell was based on principles of 25° Ekman drift (Depelche-Ellman, at all., 2016, Lepparanta and Myrberg, 2009) of prevailing wind for the period of 2012-2016;
- **Direction of wave to the coast** derived from wave modelling results done by Kriauciuniene J. (2012) using MIKE 21 hydrodynamic module systems Nearshore Spectral Wind-Wave Module (NSW);
- **Freshwater discharge zone/distance from the river mouth** – was derived from the average simulated circulation patterns at the surface and at the bottom (ECODUMP, 2013);

The entire coast of Lithuania was divided into 87 spatial cells of 1 km^2 each (Fig. 2). A straight line for the coastline, in a specific coastal cell, was taken as a basic line in order to estimate the angular impact of currents, wind, and waves (Fig. 8).

Further on, a table with used coastal parameters and potential level of impact to each of the coastal cell (Fig. 2) was developed. (Table 2). The impact ranking was done using ArcMap's equal distance function.

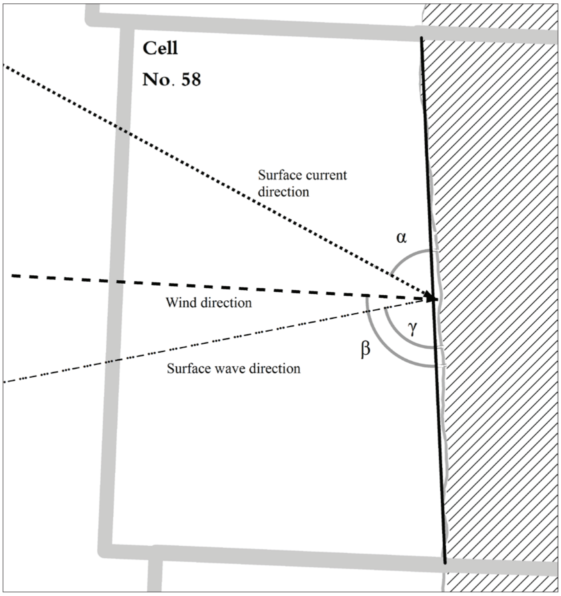

Figure 8. Schematic example of estimation of directions of: surface current (α), wind direction (β) and surface wave (γ).

8 pav. Pavyzdinė schema vaizduojanti kampo nustatymą tarp kranto linijos ir: paviršinės vandens srovės (α), vėjo krypties (β) bei priekrantės srovės (γ).

Table 2 **Applied parameters and scales for coast exposure to marine litter pollution evaluation.**

2 lentelė. **Kranto savybių kaupti jūrą teršiančias šiukšles analizėje panaudoti parametrai ir jų vertės.**

Nature of parameter	Parameter	Description	Impact level					Weighting value
			Very low (1)	*Low (2)*	*Medium (3)*	*High (4)*	*Very high (5)*	
Anthropogenic pressure to coast	Urbanization level	Buildings/ km^2	0-172	173-344	345-517	518-689	690-861	0.083
	Accessibility	Beach entrances/cell	0-6	7-11	12-17	18-22	23-28	0.083
	Indirect pollution	Trash bins/ cell	0-37	38-74	75-112	113-149	150-186	0.083
	Attendance level	SUM photo tags/ cell	0-78	79-156	157-233	234-311	312-389	0.083
	Distance to shipping rout	Kilometres	40 - >50	30 - 40	20 - 30	10 -20	0 - 10	0.083
	Distance to harbour							0.083

Nature of parameter	Parameter	Description	Impact level					Weighting value
			Very low (1)	*Low (2)*	*Medium (3)*	*High (4)*	*Very high (5)*	
Natural factor	Prevailing wind	Degrees of an angle towards the coastline	0-20	20-40	40-60	60-80	80-90	0.125
	Prevailing surface current							0.125
	Direction of the wave to the coast							0.125
	Fresh water discharge zone/distance from the river mouth	Curronian Lagoon discharge, surface current layer velocity (cm/s) zones	0-3	3-5	5-8	8-10		0.125

The level of coast exposure to marine litter pollution was calculated as follows:

$$\mathbf{EXP_{ML}} = f_{AP} + f_{NP} \quad (1),$$

where f_{AP} – a sum of anthropogenic pressure to coast parameters ranking (Impact level value) multiplied by a weighting value and f_{NP} – a sum of impacts from natural factors to coast parameters ranking (Impact level value) multiplied by a weighting value (W).

In this study weighting value (W) of each coast exposure to marine litter pollution parameter was calculated based on the formula:

$$\boldsymbol{W} = \frac{1}{2 \times P_n} \quad (2),$$

where P_n is the number of different nature parameters.

The level of coastline exposure to marine litter pollution value ($\mathbf{EXP_{ML}}$) was calculated for every coastal cell. Based on the $\mathbf{EXP_{ML}}$ value range (minimum 1.000 and maximum 4.875) five levels of coast exposure to marine litter were determined (Table 3).

Table 3. **Levels of coast exposure to marine litter pollution and range.**

3 lentelė. **Kranto savybių kaupti jūrą teršiančias šiukšles lygis ir reikšmių skalė.**

Level of coast exposure to marine litter pollution	Range
Very low	1.000 – 1.775
Low	1.7751 – 2.550
Medium	2.551 – 3.325
High	3.3251 – 4.10
Very high	4.11 – 4.875

3.4. Macro-litter source determination

3.4.1 Matrix Scoring Technique

Current study was based on the adapted litter source identification methodology developed by Schernewski et al. (2016). The most common (>1 % of total beached marine litter amount) items, found at the beach were attributed to the defined material type categories: artificial polymers, paper, glass, metal, rubber, textile, and category "other". Furthermore, all items were identified and categorized according to the OSPAR macro-litter monitoring methodology (OSPAR Commission, 2010).

The next step was an identification of littering source based on an estimated likelihood to be originated from main marine litter sources, such as tourism (beach users and all kind of recreational activities on the beach and in the surf zone); sewage related debris; shipping; offshore installations and fishing related debris. Least possible/ not realistic for the region, of investigation sources were eliminated.

In cases when collected litter could not be attributed to a single source, a percentage allocation method was used. The method allows defining the different likelihood-scores for an item originating from a given source: very unlikely (score 0), unlikely (1), possible (2), likely (3) and very likely (4) (Fig. 9A). The scoring was based on a practical knowledge/experience obtained during the field sampling and considering two functions: the association to the pollution source and the level of an item definition (Fig. 9A).

The probability that an item originates from a source was the result of the score per source ($Tsource_x$) multiplied with the total percentage of items found per particular item (A), divided by the sum of likelihood-scores for particular item (Formula no. 3).

$$T = \sum \frac{A \times Tsource_x}{Tsource_n} \quad (3),$$

where A- item percentage from all items found in a location, *Tsource*$_x$ – a likelihood-score of item originating from a given source, *Tsource*$_n$ – a sum off all likelihood-scores of an item originating from an analysed sources. The same methodology was applied for all macro-litter beach survey sites.

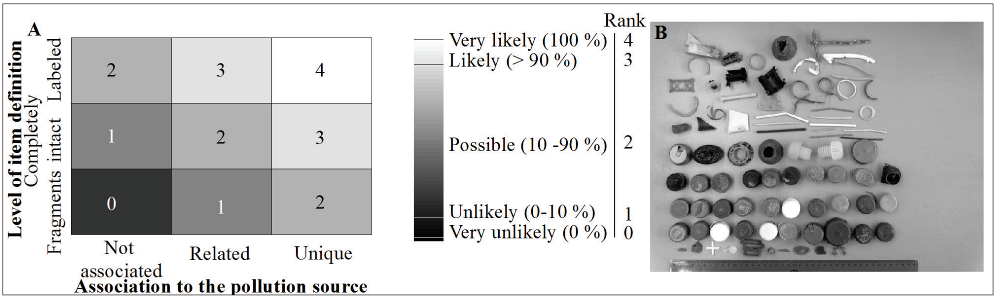

Figure 9. Matrix Scoring Technique (after Tudor and Wiliams, 2004) for the determination of potential pollution sources. A – Matrix of item allocation to possible pollution source, B – examples of litter items found during macro-litter surveys.

9 pav. Potencialių taršos šaltinių nustatymas, naudojant Matricinį rangavimo metodą (pagal Tudor ir Wiliams, 2004). A – Šiukšlės priskyrimo galimam taršos šaltiniui vertinimo matrica, B – makrošiukšlių tyrimo metu rastų šiukšlių pavyzdžiai.

3.4.2 Indicators of litter source

Application of specific indicators while identifying the litter source was used by OSPAR and applied in several studies (e.g. Gago et al., 2014). This approach was based on the litter items that are easy to identify and attribute to one or another litter category (Table 4) – i.e. pollution source. In this case, only a small number of litter was taken into account and litter monitoring did not provide full information on the share and importance of the different pollution sources for a given region. It, however, was used to calculate trends of an input from the main sources of pollution.

***Table 4.* Indicator-items used in the OSPAR Beach Litter monitoring programme to determine the potential pollution source (Veiga et al., 2016).**

***4 lentelė.* Daiktai-indikatoriai naudojami nustatant galimą taršos šaltinį pagal OSPAR paplūdimio monitoringo programą (Veiga ir kt., 2016).**

Source	Indicators
Fisheries, including aquaculture	Jerry cans, Fish boxes, Fishing line, Fishing weights, Rubber gloves, Floats/buoys, Ropes/cords/nets <50cm, and >50cm, respectively, Tangled nets/cords, Crab/lobster pots, Octopus pots, Oyster nets and mussel bags, Oyster trays, Plastic sheeting from mussel culture (”Tahitians”).
Galley waste from shipping, fisheries and offshore activities (non-operational waste)	Cartoons/tetrapacks, Cleaner bottles, Spray cans, Metal food cans, Plastic gloves, Plastic crates.
Sanitary and sewage-related waste	Condoms, Cotton bud sticks, Sanitary towels/panty liners/backing strips, Tampons/Tampon applicators.
Shipping, including offshore activities (operational waste)	Strapping bands, Industrial packaging, Hard hats, Wooden pallets, Oil drums (new and old), Light bulbs/tubes, Injection gun containers,
Tourism and Recreational activities	Cigarette butts, 4-6-pack yokes, Plastic shopping bags, Plastic bottles/containers for drinks, Metal bottles/containers for drinks, Plastic food containers, Glass bottles, Crisp/sweets packets and lolly sticks.

3.5. Spatial and statistical analysis of seafloor and beached marine litter

The Statistical Package for the Social Sciences (SPSS) statistics software was used in order to perform the statistical analyses. A non-parametric Spearman rank correlation was used to determine the reliability of pollution source determination and the coast exposure to marine litter pollution values for different beaches. Also a Spearman rank correlation was used to confirm relationships between the SML amounts and the geomorphologic region of the Lithuanian marine area, and to justify the seasonal variation of beached marine litter amounts.

To obtain more information on similarities of pollution with marine litter, two different cluster analyses applying the Ward method, with Euclidean distance as measure of proximity, were carried out for all macro-litter survey beaches:

- Cluster analysis No. 1. An overall pollution level cluster analysis, where mean BML abundance values of all survey beaches were used as an input data;
- Cluster analysis No. 2. A complete linkage cluster analysis, where mean abundance values of nine most common beach litter items were used as an input data.

In order to analyse the similarities of different beaches on pollution level based on the data obtained from the macro-litter surveys, a t-test was performed. The mean amount of macro-litter items was used as an input parameter for a comparison of means.

For the spatial analysis of marine litter distribution and the accumulation patterns in the LMA and the Lithuanian coast the ArcMap software was used. In order to analyse marine litter distribution in the Lithuanian marine area or in the coast a spatial frame (the fishnet cells) was created. The size of rectangular cells was determined based on an *in situ* data: a mean length of a bottom trawling survey (3.5 km) and a mean GPS error noted during the field campaigns (5 metres). The amount of marine litter on the seafloor or the beach per fishnet cell formed a weighted feature class. Two ArcMap' Spatial Statistics toolbox tools (Hot Spot analysis using the Getis-Ord Gi* statistic with Euclidean distance as a feature proximity parameter and Cluster and Outlier analysis (Anselin Local Morans I) were used in order to map clusters of the marine litter (Fig. 10). Only a statistically significant output was used for mapping the marine litter clusters.

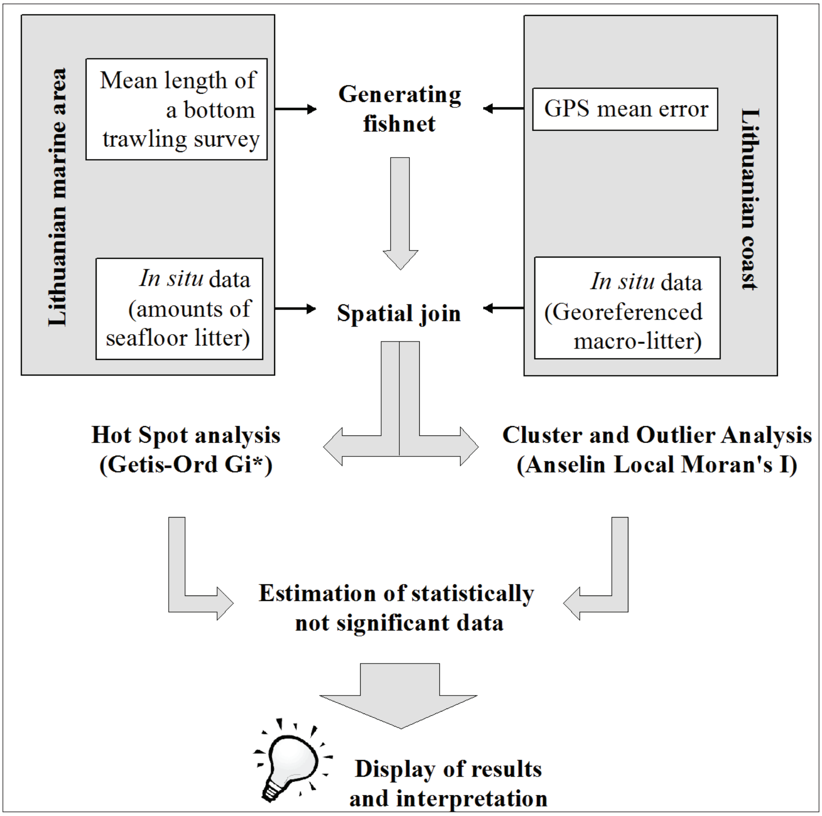

Figure 10. Spatial clusterisation of seafloor litter and beached macro-litter scheme.

10 pav. Jūros dugną bei paplūdimius teršiančių šiukšlių erdvinės analyzės shema.

4

Results

4.1. Characteristics of litter in the marine and coastal environment

4.1.1 Beached marine litter

The amount of beached marine litter (BML) in the Lithuanian beaches ranges from 31 item/100 m to 422 items/100m with an average amount of 164.7±92.8 item per 100 m long transect of the beach (Table 5).

Table 5. **Parameters of collected beached marine litter.**

5 lentelė. **Paplūdimiuose surinktų šiukšlių statistiniai rodikliai.**

Survey location/ Parameters	N	MAX	MEAN	MIN	STDEV	Range items/100m	Macro-litter density, items/m^2
Nida	4	104	60.5	31	32.0	73	0.009±0.005
Juodkrante	4	143	80.5	37	44.7	106	0.021±0.012
Nordbalt	4	140	118.5	94	19.3	46	0.016±0.003
Smiltyne	4	187	120.5	57	55.6	130	0.018±0.008
Klaipeda	16	422	299.2	168	79.3	254	0.051±0.014

Survey location/ Parameters	N	MAX	MEAN	MIN	STDEV	Range items/100m	Macro-litter density, items/m^2
Karkle	14	319	204.7	110	68.8	209	0.064±0.022
Nemirseta	16	211	149.9	82	39.4	129	0.035±0.009
Palanga	16	211	133.3	35	61.2	176	0.018±0.008
Sventoji S (South)	4	146	91.3	55	39.7	91	0.010±0.005
Sventoji N (North)	4	128	82.3	35	41.3	93	0.017±0.009
OVERALL	86	422	167.4	31	92.8	391	0.028±0.016

Abbreviations: N – a number of macro-litter surveys; MAX – a maximum amount collected; MEAN – a mean amount; MIN – a minimum amount collected; STDEV- a standard deviation; Range – a measure of the spread of a variable (the difference between the largest and the smallest observations).

An overall comparison of the total amount of the beached marine litter in the different beaches along the Lithuanian coast is presented in Fig. 11. The largest number of the BML was recorded in Klaipeda city beach (Melnrage), where 299.2±79.3 items per 100 m of beach was found as an average. The least pollution by the marine litter was observed in the Nida beach, where only 60.5±32.0 item as an average was recorded (Table 5).

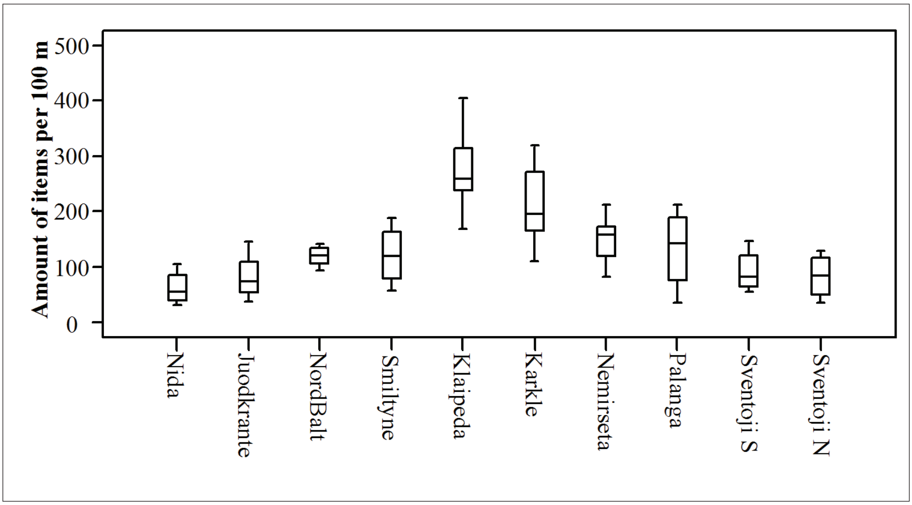

Figure 11. Variation of total beached marine litter amount at Lithuanian beaches (indicating: minimum, maximum, mean amount and tolerance interval).

11 pav. Jūrą teršiančių šiukšlių kiekis Lietuvos paplūdimiuose (nurodant: minimalią, maksimalią ir vidutinę reikšmes bei tolerancijos intervalą).

Figure 12 indicates that the highest density of beached marine litter was recorded in the Karkle beach - 0.064±0.022 items/m^2 and the lowest in the Nida beach - 0.009±0.005 items/m^2 (area of the beach derived from GDB10LT orthographic pictures).

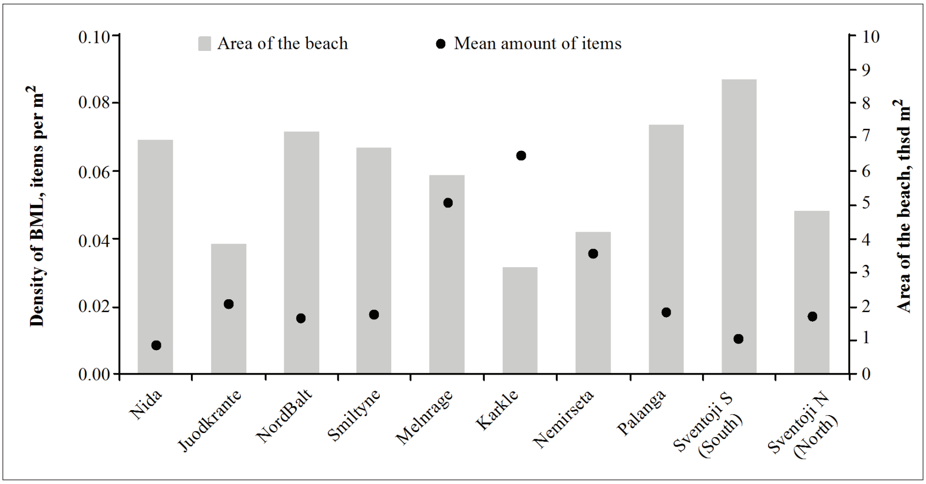

Figure 12. Variation of macro-litter density in different beaches along Lithuanian coast.

12 pav. Jūrą teršiančių šiukšlių tankis skirtinguose Lietuvos Baltijos jūros paplūdimiuose.

The seasonal variation of marine litter amount in the Lithuanian beaches is presented in Fig. 13. A positive weak Spearman rank correlation (ρ=0.393, $p<0.01$) between the seasons and the amount of BML was determined. The mean amount of BML varies from 215.3±103.2 items/100m in autumn to 127.9±73.2 items/100m in winter.

Figure 14 presents the results of analysis of the litter material type distribution in the beaches of interest. The artificial polymers are the dominant material type and contribute to 83 % of all items found.

The plastic/polystyrene pieces (diameter 2.5 cm > < 50 cm) amounted to 41.6 % of all items found and were most abundant BML type (Table 6). The cigarette butts were the second most common beached marine litter item in the Lithuanian coast (13.0 % of all items found). Only two litter types among 12 most common beached marine litter items - fragments of glass (attributed to category – “Other glass items”) (3.1%) and metal drink cans (1.6 %) do not belong to “not artificial polymer” group.

Approximately 22 type marine litter items, out of 121 suggested by the OSPAR or 165 suggested by the TSG ML Master list, were found during the beach surveys.

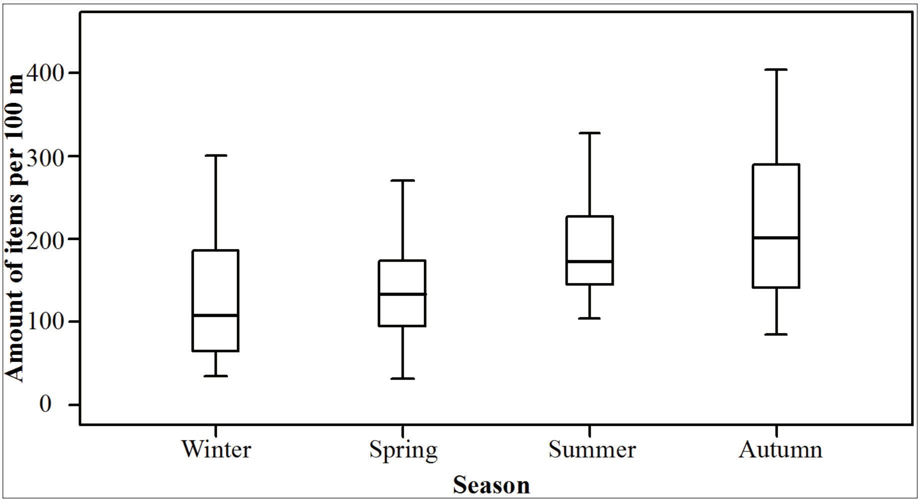

Figure 13. Seasonal variation of the BML amount in Lithuanian beaches (indicating: minimum, maximum, mean amount and tolerance interval).

13 pav. Jūrą teršiančių šiukšlių kiekio sezoninė kaita Lietuvos paplūdimiuose (nurodant: minimalią, maksimalią ir vidutinę reikšmes bei tolerancijos intervalą)

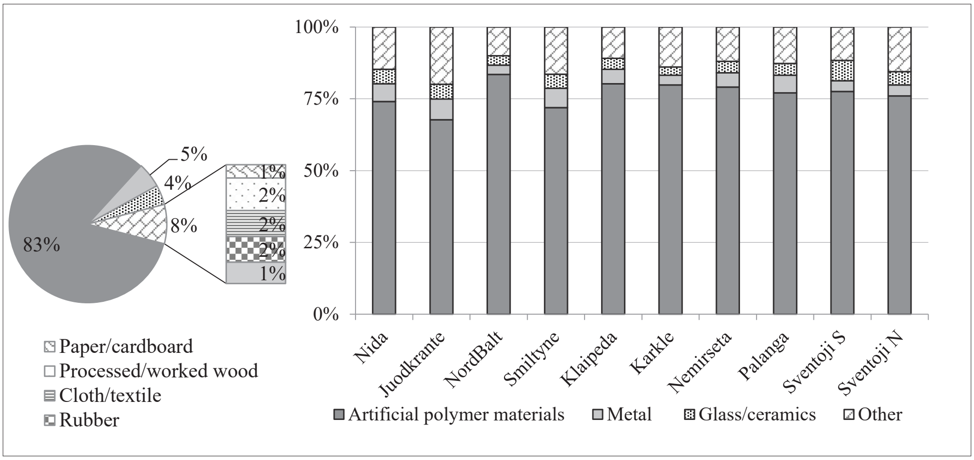

Figure 14. Type of beached marine litter per survey area.

14 pav. Lietuvos paplūdimius teršiančių šiukšlių medžiagos tipas.

***Table 6.* Most abundant beached marine litter items in Lithuanian beaches.**

***6 lentelė.* Lietuvos paplūdimiuose dažniausiai randamos šiukšlės.**

Order	OSPAR Code	TSG_ML General code	UNEP Code	General name	Material type	Total amount	%
1	46	G74	n.d.	*Plastic/polystyrene pieces 2,5 cm > < 50 cm	AP	5996	41.6
2	64	G27	PL11	Cigarette butts	P/ AP	1874	13.0
3	32	G50	PL19	String and cord (diameter less than 1 cm)	AP	826	5.7
4	15	G20	PL01	Caps/lids	AP	752	5.2
5	93	G208	GC06	*Other glass items	G	447	3.1
6	3	G4	PL07	Small plastic bags, e.g., freezer bags	AP	436	3.0
7	4	G6	PL02	Drinks (bottles, containers and drums)	AP	407	2.8
8	33	G56	PL20	Tangled nets/cord/rope and string	AP	372	2.6
9	6	G10	PL06	Food containers incl. fast food containers	AP	324	2.3
10	77	G178	ME02	Bottle caps	M	303	2.1
11	21	G33	PL06	Cups	AP	278	1.9
12	78	G175	ME03	Drink cans	M	235	1.6

**Non-identifiable fragment items, which were removed from input data in additional cluster analysis*

Abbreviations: AP – artificial polymer material, P – paper, G- glass, M – metal, n.d. – not determined

4.1.2 Marine litter on the seafloor

Figure 15 shows that in the Lithuanian marine area an average of 111.6±108.2 items per km^2 of marine litter on the seafloor (SML) could be found. A total of 41 bottom trawling surveys (83.7 %) resulted in catching at least one SML item. The comparison of composition of found items revealed that the artificial polymers were the dominant (71 %) material type. The measured/identified density of marine litter items on the seafloor of different sediment type did not reveal any clear tendencies. Nevertheless, the sea bottom trawling surveys on pebble and gravel sediment resulted in the highest mean amount of the SML (163.6±160.2 items/km^2, N=3), representatively mud (N=17, 117.7±125.2 item/km^2), fine sand (N=15, 115.0±111.9 item/km^2) and silt (N=13, 129.2±81.0 item/km^2).

An overall comparison of the seafloor litter in different geomorphologic regions in the LMA is presented in Table 7. The largest number of the SML during a single trawling campaign was recorded in the Slopes of Gotland and Gdansk basins, where 24 items per 3.2 km of bottom trawling was caught. The Palaeovalley of Nemunas River resulted in a highest density of the SML (N= 6, 171.9±98.6 items/km^2), followed by the Slopes of Gotland and Gdansk basins (N = 19, 135.8±119.9 items/km^2) and the Curonian-Sambian Plateu (N= 4, 133.6±132.3 items/km^2) (Table 7).

Table 7. **Parameters of marine litter items collected from the seafloor.**

7 lentelė. **Nuo jūros dugno surinktų** šiukšlių statistiniai rodikliai.

Surveyed geomorphologic region	**N**	**MAX**	**MEAN**	**MIN**	**STDEV**	**Mean density of the SML, items/km^2**
Curonian-Sambian Plateu	4	13	6.00	0	5.70	133.6±132.3
Gdansk basin	9	15	3.78	0	4.92	64.3±69.4
Klaipeda bank	3	9	5.00	1	4.00	35.3±26.3
Klaipeda-Ventspilis plateu	8	6	2.30	0	2.41	86.2±115.1
Palaeovalley of Nemunas River	6	14	10.00	4	4.43	171.9±98.6
Slopes of Gotland and Gdansk basins	19	24	7.16	0	5.82	135.8±119.9
OVERALL	49	24	5.73	0	5.27	111.6±108.2

Abbreviations: N – a number of surveys; MAX – a maximum amount of items collected; MEAN – a mean amount of litter items per bottom trawling campaign; MIN – a minimum amount of items collected; STDEV- a standard deviation.

The plastic sheets resulted as the most common seafloor marine litter item and resulted to a total of 61 (20.8 %) items found. Only three not artificial polymer items were among top ten most common seafloor litter items: Other items (F3), which usually were textile/cloth or foam materials, Other rubber (C6) and Wood (processed) (E1) (Table 8).

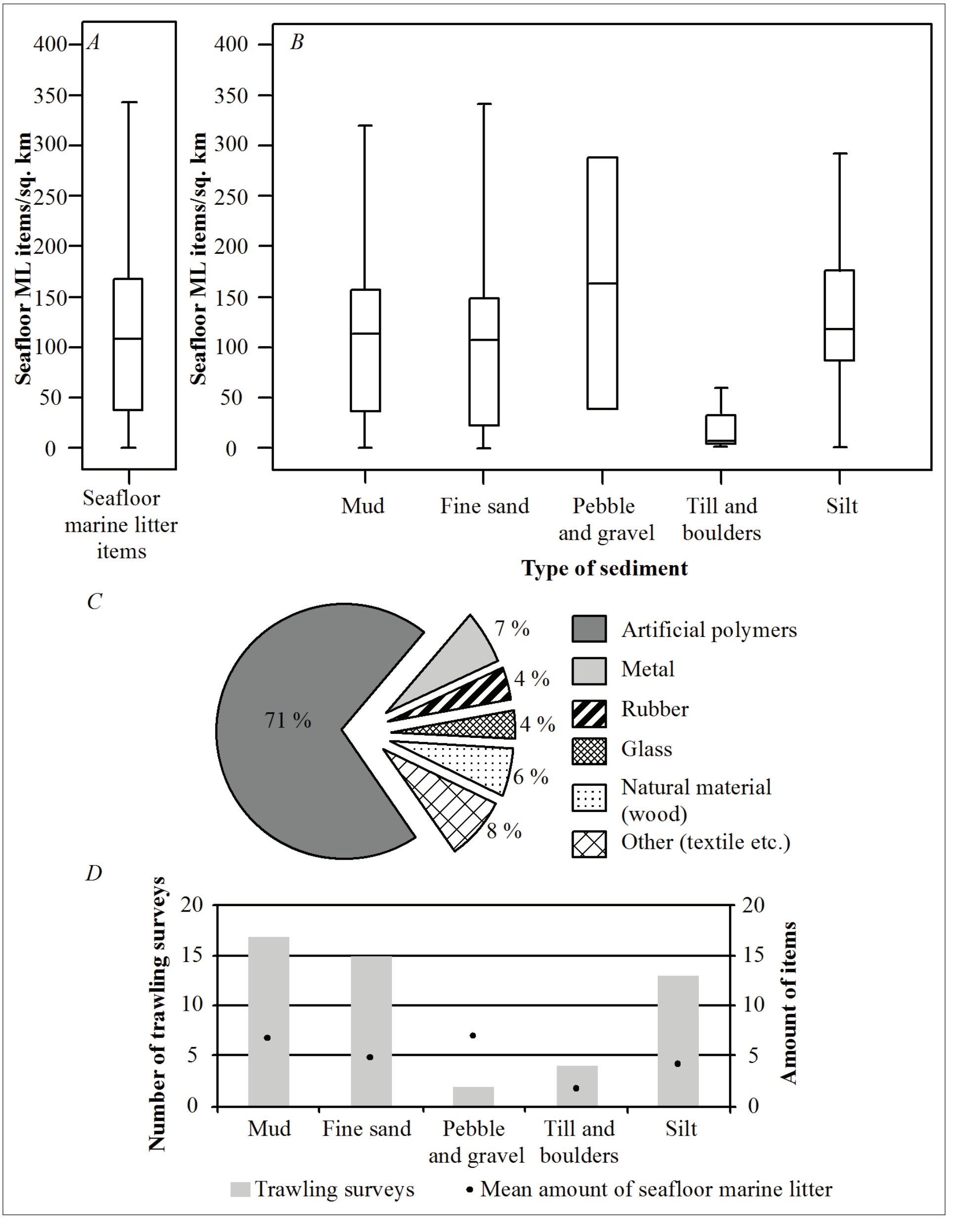

Figure 15. Marine litter on the seafloor: total amount of marine litter on the seafloor (A); amount related to bottom sediment type (B), composition of marine litter collected from the seafloor (C) and frequency of bottom trawling surveys and mean amount of litter items found (D) (indicating: minimum, maximum, mean amount and tolerance interval).

15 pav. Šiukšlės jūros dugne: bendras kiekis (A), kiekis priklausomai nuo dugno nuosėdų tipo (B), jūros dugne rastų šiukšlių sudėtis (C), jūros dugno tralavimų skaičius ir vidutinis šiukšlių kiekis (D) (nurodant: minimalią, maksimalią ir vidutinę reikšmes bei tolerancijos intervalą).

Table 8. **Results of the SML survey in the Lithuanian marine area.**

8 lentelė. **Šiukšlių jūros dugne tyrimo rezultatai.**

Order	ICES code	Description	N	%
1	A2	Plastic sheet	61	20.8
2	A3	Plastic bag	53	18.1
3	A14	Other plastics	32	10.9
4	F3	Other (Textile, etc.)	21	7.2
5	A7	Synthetic rope	15	5.1
6	A6	Plastic fishing line (entangled)	13	4.4
7	C6	Other rubber	12	4.1
8	A1	Plastic bottle	11	3.8
9	E1	Wood (processed)	11	3.8
10	A10	Plastic strapping band	10	3.4

Abbreviations: N – a total amount of found items.

4.1.3 Large micro- and meso-litter

A total of 746 m^2 of the surface sediment was sieved and a mean amount of 1.80 large micro- and meso-litter particles was found in the Lithuanian Baltic sea beaches (Table 9). The Melnrage (2.48±1.03 items/m^2) and the Panalga (2.13±0.38 items/m^2) beaches revealed to be the most polluted with large micro- and meso-litter particles. The NordBalt survey location, despite largest area monitored (213 m^2) resulted in a lowest amount (1.20±0.46 items/m^2) of smaller fraction beached marine litter.

The results of two beached large micro- and meso-litter survey methods: Frame-method (Method No. 1) and Rake (Method no. 2) are presented in Figure 16. The method No. 1 resulted with a lower mean (17.89±13.16) and a higher dispersion in an amount of beached marine litter particles, if compared to the method No. 2 (36.25±9.81).

Table 9. **Parameters of micro- and meso-litter survey in the beaches.**
9 lentelė. **Mikro- ir mezošiukšlių paplūdimiuose tyrimo rodikliai.**

Parameters/ Survey location	Palanga	Giruliai	Melnrage	Smiltyne	NordBalt	Overall
Number of surveys performed (N)	5	6	5	4	5	25
Total area surveyed (m^2)	147	141	127	118	213	746
Mean amount/m^2	2.13±0.38	1.74±1.30	2.48±1.03	1.60±2.00	1.20±0.46	1.80±1.24

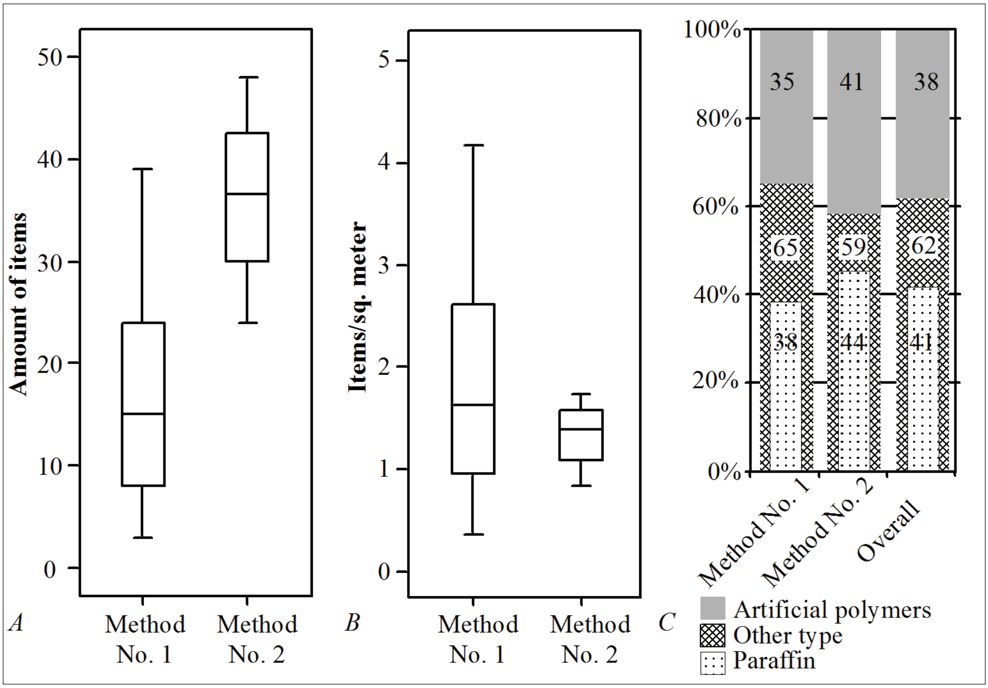

Figure 16. Amount of beached large micro- and meso-litter vs survey method used: total amounts (A), items per area (B) and composition of material type (C) (indicating: minimum, maximum, mean amount and tolerance interval).

16 pav. Dviem metodais tirtų didesnių mikro- ir mezošiukšlių paplūdimiuose kiekio priklausomybė nuo pasirinkto tyrimo metodo: bendras šiukšlių kiekis (A), tankis (B) ir sudėtis (C) (nurodant: minimalią, maksimalią ir vidutinę reikšmes bei tolerancijos intervalą).

A comparison of spatial variability between the two methods revealed that despite a slightly lower mean amount (1.40±0.37) Rake method (the method No. 2) had significantly lower dispersion compared to Frame-method (the method No. 1) (2.07±1.38) (Fig. 16 A,B).

The methods did not show significant differences in the particle material type distribution (Fig. 16 C). The artificial polymers contributed to 38 % of all particles found. The paraffin particles (category – “Other type”) were dominant item during the beached large micro- and meso-litter surveys and contributed to 41 % of all items found.

4.2. Spatial distribution of marine litter

4.2.1 Results of spatial clusterisation

The overall comparison of the marine litter accumulation tendencies using the Hot Spot analysis revealed that litter accumulates close to the beach infrastructure (dressing cabins, buildings) (Fig. 17). Also the majority of collected items accumulated around 50 meters from the beach entrance. A statistically significant item concentration close to the dressing cabins and buildings confirms, that the majority of this litter originates from the land sources – are brought by the people visiting the beach.

The cigarette butts revealed to have a similar spatial dispersion pattern as all collected beached marine litter items. A wider, compared to cigarette butts, spatial dispersion pattern of the artificial polymer items may be a result of wind, distributing light weighted items on the beach.

A comparison of two spatial clustering techniques allowed clarifying statistically significant cells where high values of the seafloor litter could be found and excluding potential Hot Spots where a seldom high value influences surrounding cells.

The spatial statistics analysis revealed the near shore (Klaipeda-Ventspilis plateu and Curonina-Sambian plateu) areas does not result as a statistically significant SML accumulation zones. The higher density of the seafloor litter accumulation zones is evident in the Central part of the Lithuanian marine area and in the Paleovalley of Nemunas River (Fig. 18). The clusters of the SML are located either in a close proximity of or directly below the highest ship traffic zones in the LMA.

The further offshore regions in the LMA (the Klaipeda band or the Gotland basin) did not show any patterns of the seafloor marine litter accumulation zones (the statistically significant clusters).

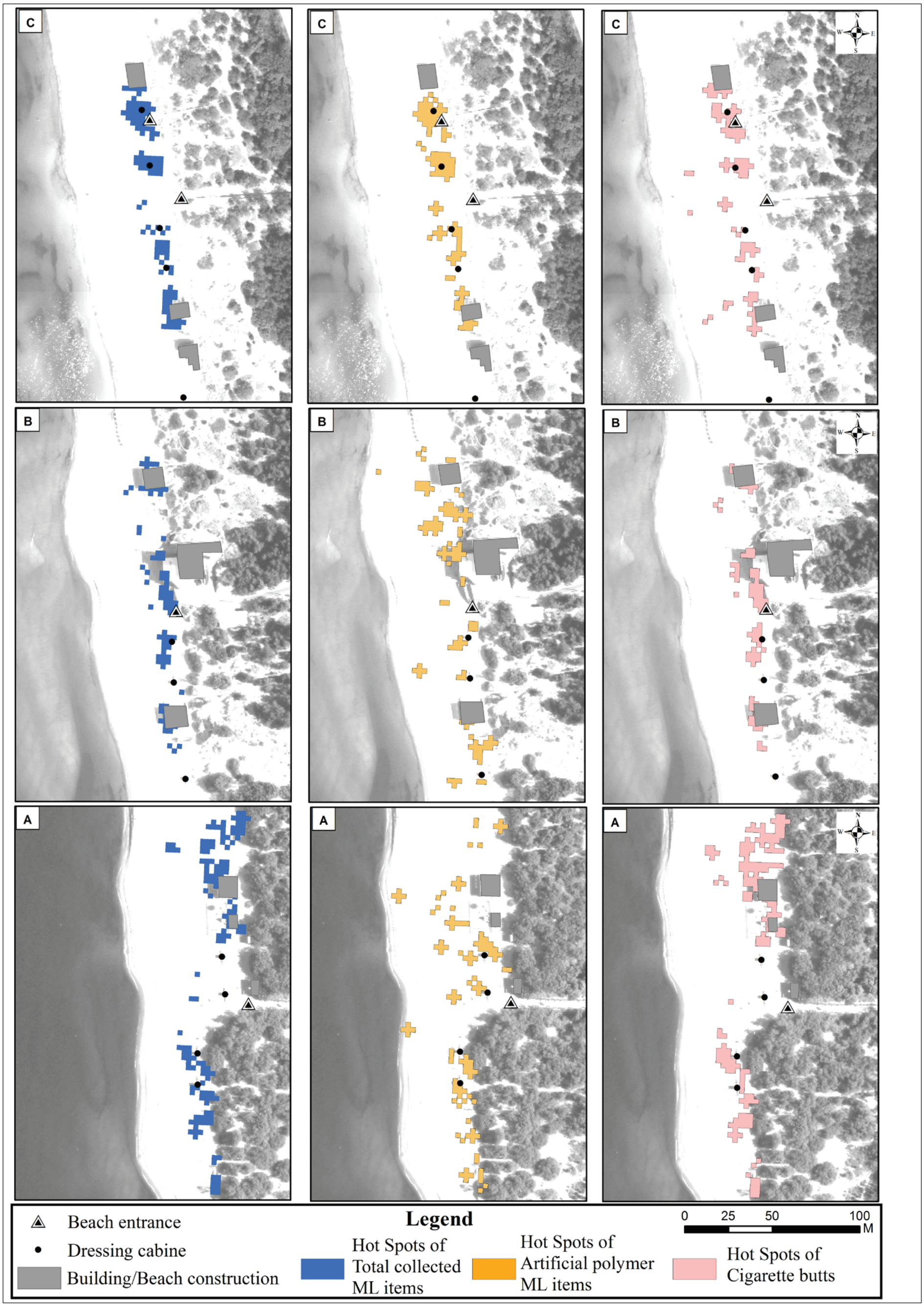

Figure 17. Marine litter accumulation in: A- Melnrage I, B- Melnrage II, C- Giruliai beaches.

17 pav. Jūrą teršiančių šiukšlių akumuliacija: A – Pirmosios Melnragės, B – Antrosios Melnragės, C- Girulių paplūdimiuose.

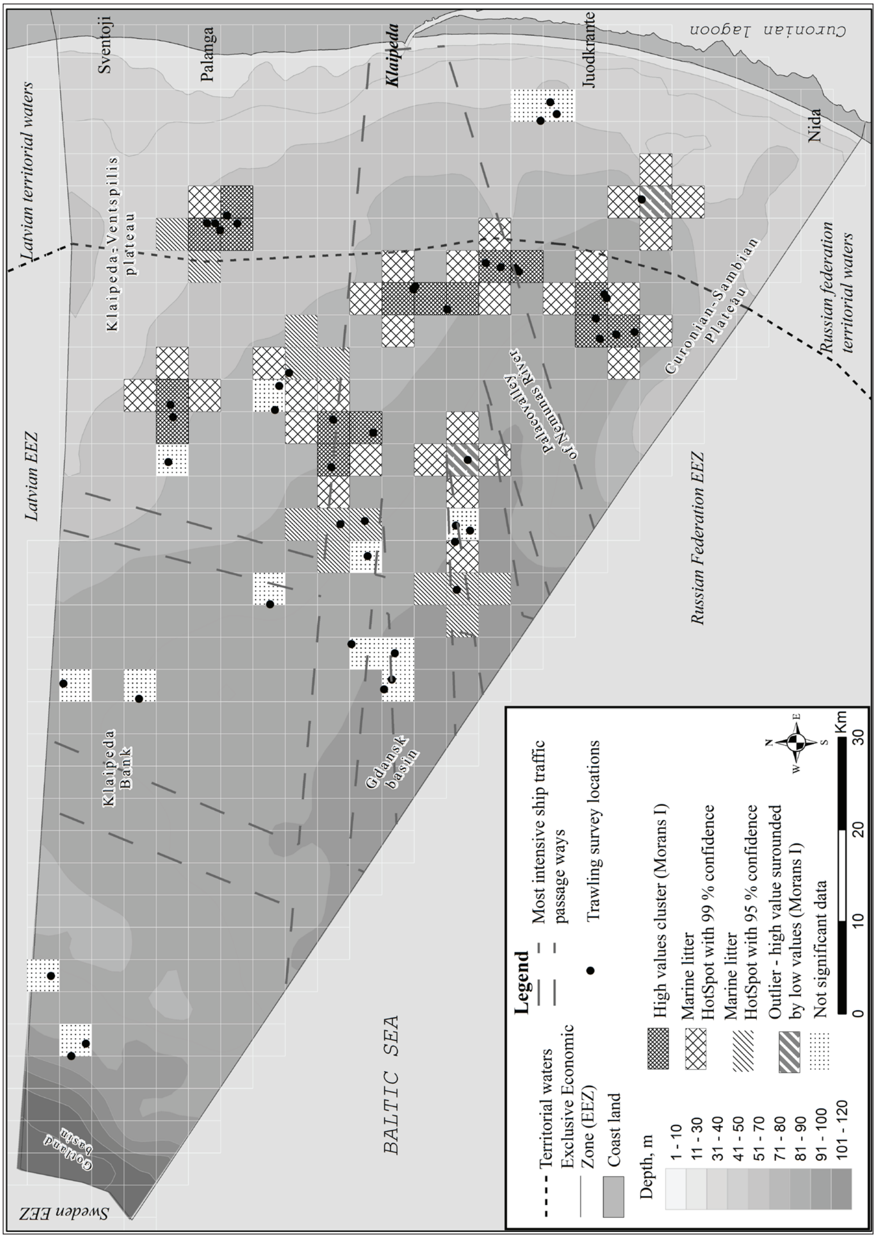

Figure 18. Zones of litter accumulation on the seafloor.

18 pav. Jūrą teršiančių šiukšlių akumuliacijos zonos jūros dugne.

4.2.2 Results of hierarchical and statistical clustering

After applying the Ward method, two clear groups (Group 1 and Group 2) according to the pollution level were determined (Figure 19 A), where the first group had clear sub-groups (Group 1a and group 1b). The first sub-group (group 1a) contained the least polluted survey sites: the Juodkrante, the Sventoji N, the Sventoji S and the Nida, which also were most northern and southern locations of this study. The second sub-group (group 1b) contained a mixture of wild beaches (the NordBalt), intermediate attendance (the Nemirseta) and more touristic (the Palanga, the Smiltyne) sites. The most polluted survey sites (Klaipeda and Karkle) formed a separate group (Group 2). The second group gave a hint on how urbanisation level influences the amount of beached marine litter.

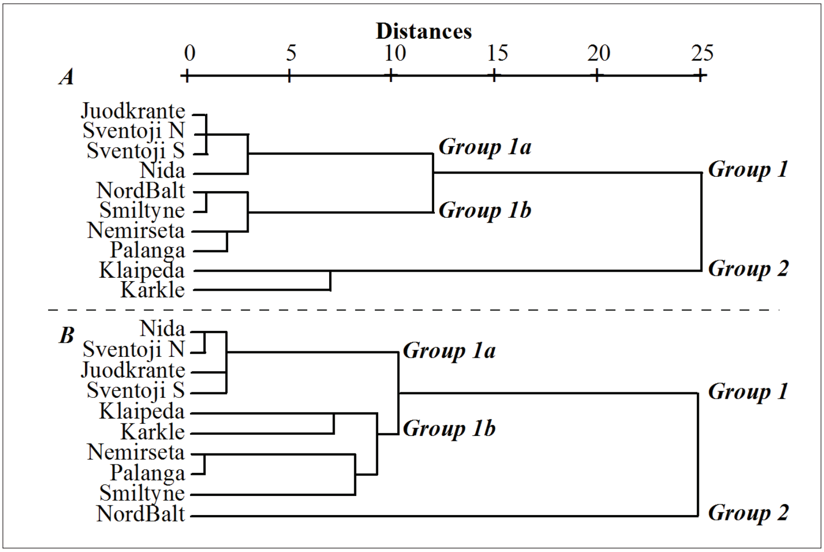

Figure 19. Clusterization of the studied beaches: A- An overall pollution level cluster analysis; B - A complete linkage cluster analysis.

19 pav. Tirtų paplūdimių klasterinės analizės rezultatai: A – vertinant bendrą užteršumo šiukšlėmis lygį, B –vertinant randamas šiukšles paplūdimiuose.

The initial pairing of sampling sites, which are in a close topographic proximity (the Klaipeda and the Karle, the Nemirseta and the Palanga, the NordBalt and the Smiltyne) was noted. Performed t-test (Table A1, in the Annex) analysis confirmed the statistically significant similarities of the mean amounts between neighbouring survey sites, except of the Klaipeda and the Karkle case. The mean amounts of beached marine litter in the Klaipeda and the Karkle were statistically different when compared with other survey sites. The mean amounts of beached marine litter in the Karkle ($t (13) = 2.03$, $p=0.064$) and the Nemirseta ($t (15) = -1.77$, $p=0.096$) represented an overall beached marine pollution level for the Lithuanian coast (Table 8).

A complete linkage cluster analyses with nine most common and identifiable items as an input data revealed to have a similar output to an overall pollution level analysis. First group (group 1a) was formed of the same four, topographically distant from the middle of a study area and the least polluted, survey sites (the Nida, the Sventoji N, the Juodkrante, the Sventoji S) (Fig. 19 B). The second subgroup (group 1b) united all remaining urban and touristic beaches. The NordBalt survey site (wild beach) formed an outlying cluster (Group 2), which indicates the beached marine litter composition difference between the anthropogenically pressured (tourism, urbanisation, etc.) and the wild beaches.

4.3. Coast exposure to marine litter pollution

The Lithuanian coast exposure to marine litter pollution analysis (Fig. 20 C) revealed that for more than two thirds of the coast levels of exposure could be considered as low (34.5%) and medium (29.9%). The sections with the highest level of the coast exposure to marine litter pollution (5.7 %) in the Lithuania were in the mainland part and areas close to the largest settlements (Klaipeda and Palanga) (Fig. 20 B). The coast sections with the lowest levels of exposure to marine litter pollution made around 19.5 % of the Lithuanian coast and mostly were located in the Southern part of the Curonian Spit or the northern part of the mainland coast (20 A, B).

The Lithuanian coastline mostly is influenced by the natural origin exposure to marine litter pollution parameters. An average of 66 % of the final exposure to marine litter pollution value, for each cell, is determined by the natural factors (Fig. 21). Klaipeda city, a largest settlement and a harbour, on the coast does have an impact on the overall distribution of the coast exposure to marine litter pollution levels in Lithuania. The increase of an anthropogenic pressure to the coast parameters significance, compared to the factors of a natural origin, is reflected by a slight inward arcing in the proportion of the exposure to marine litter pollution parameters.

When comparing the mainland and the Curonian spit coasts it is evident that the Curonian spit coast is more homogeneous, in regards of the exposure parameter proportion, whereas the mainland coast shows a clear variability (Fig. 21).

When seeing the origin of the exposure parameters proportions along the Lithuanian coastline it is evident that the anthropogenic pressures to coast parameters tend to be more significant close to the larger settlements. Figure 21 shows three clear

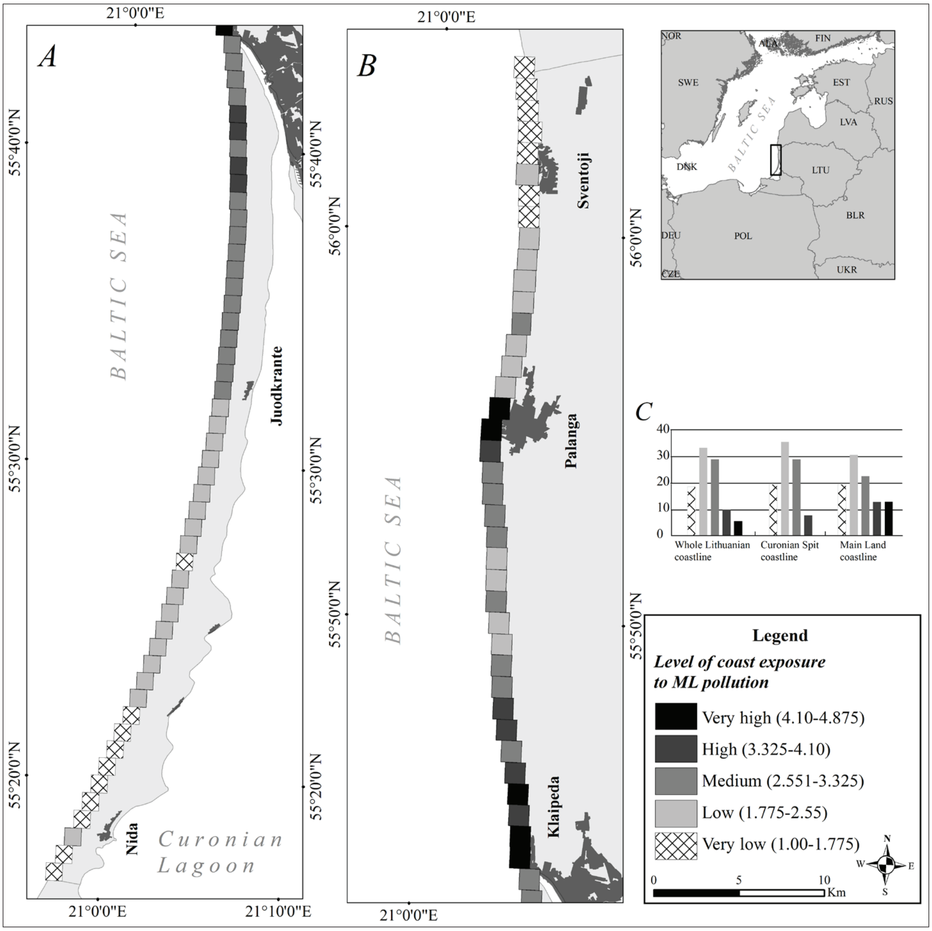

Figure 20. Lithuanian coast exposure to marine litter pollution.

20 pav. Lietuvos kranto savybių kaupti jūrą teršiančias šiukšles vertinimo rezultatai.

shifts (Cell No.50 to cell No. 55, Cell No. 70 to Cell No. 71 and Cell No. 82 to Cell No. 83) in balance of the coast exposure to marine litter pollution. This is caused by shift in the significance of coast exposure to marine litter pollution parameters. Close to Klaipeda settlement (Cell No.50 to cell No. 55) main factors causing the unbalance are the pollution through the Curonian Lagoon discharge (natural factors) and the Beach accessibility (anthropogenic pressure to coast parameter). The Palanga city peak is influenced by the increase in the anthropogenic pressure to coast factors (beach attendance, indirect pollution and urbanization level). The shift in the coast exposure to marine litter pollution close to the Sventoji settlement is mostly caused by the significant increase of urbanization and attendance levels.

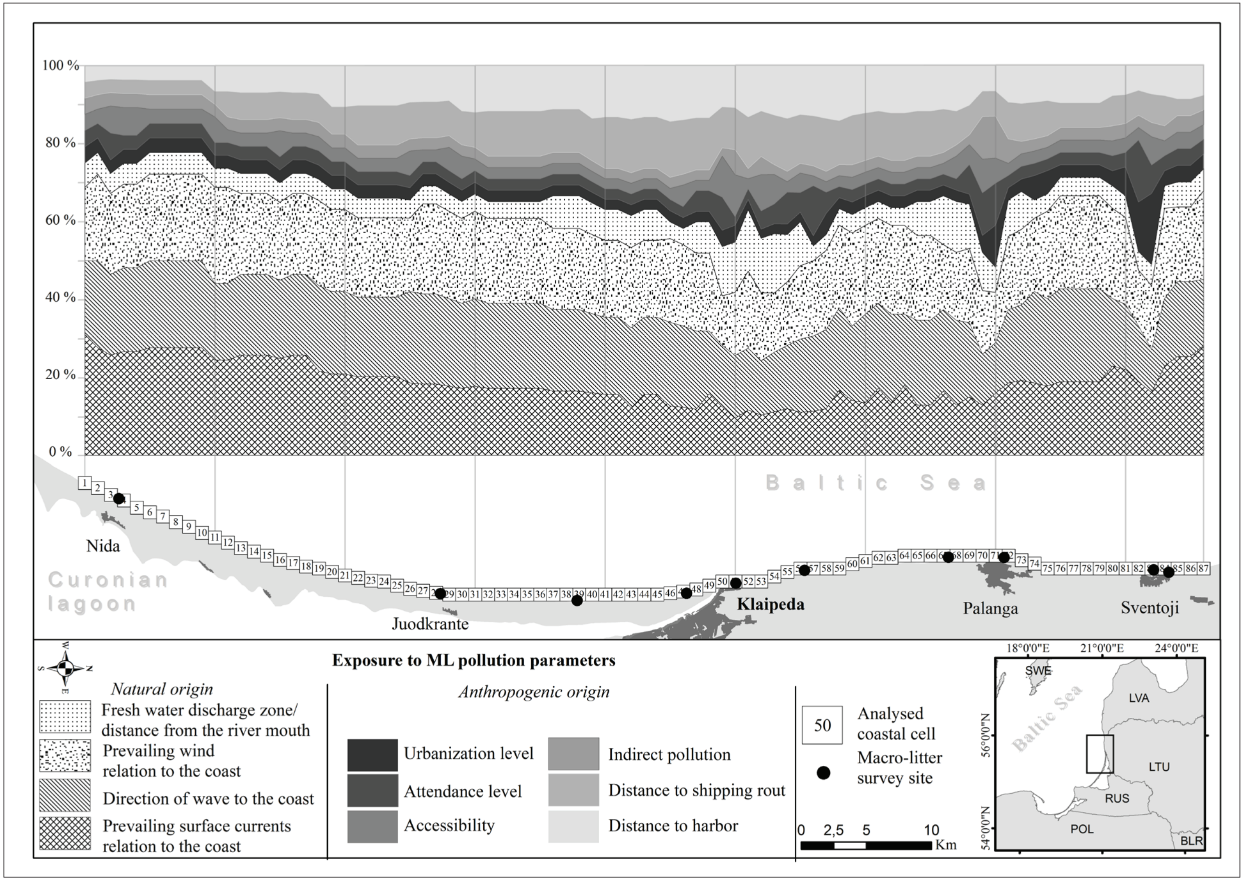

Figure 21. Cumulative analysis of parameters influencing coast pollution with marine litter.

21 pav. Kranto užteršumą šiukšlėmis lemenčių parametrų suminė analizė.

Table 10. **Spearman rank correlations (ρ) between coast level of exposure to marine litter pollution and different origins exposure parameter aggregated values (N=10).**

10 lentelė. **Spearmano ranginės koreliacijos (ρ) vertės tarp kranto savybių kaupti jūrą teršiančias šiukšles ir suminės skirtingos kilmės parametrų vertės (N=10).**

Spearman Rank correlation (ρ) with coast level of exposure																							
Mean amount		Mean amount/m^2		Cigarette butt		String		Caps		Plastic bags		Drink Bottles		Tangled net		Food container		Metal caps		Cups		Drink cans	
ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	ρ	Sig.	P	Sig.	ρ	Sig.	ρ	Sig.
.848**	.002	.791**	.006	.362	.305	.318	.371	.848**	.002	.763*	.010	.913**	.000	.788**	.007	.837**	.003	.395	.258	.680*	.030	.538	.109
Spearman Rank correlation (ρ) with cumulative value of anthropogenic pressure to coast parameters																							
.815**	.004	.585	.075	.736*	.015	.578	.080	.608	.062	.835**	.003	.720*	.019	.610	.061	.563	.090	.336	.342	.477	.163	.604	.065
Spearman Rank correlation (ρ) with cumulative value of natural factors to coast																							
.640*	.046	.692*	.027	-.006	.986	.205	.570	.727*	.017	.555	.096	.810**	.004	.717*	.020	.756*	.011	.250	.486	.706*	.022	.449	.193

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed). Abbreviations: Sig. – significance level.

The Spearman rank correlations between the calculated coast exposure to marine litter pollution values and the mean amounts of the most common beached marine litter items were always positive (Table 10). The very strong positive correlation ($\rho=0.848$, $p<0.01$) between the mean amounts of the beached marine litter and the exposure to marine litter pollution levels indicates that the coast exposure to marine litter pollution assessment allows to predict areas of higher pollution levels.

Also the very strong and the strong positive correlations between different beached marine litter items: cigarette butts ($\rho=0.736$ $p<0.05$), plastic bags ($\rho=0.835$ $p<0.01$), drink bottles ($\rho=0.720$ $p<0.05$), and the aggregated anthropogenic pressures to coast parameters value not only confirms this pollution to be anthropogenic but also proves that the method is correct. For the pollution due to the natural factors (aggregated value of natural factors to coast) drink bottles ($\rho=0.810$ $p<0.01$), food containers ($\rho=0.756$ $p<0.05$), bottle caps ($\rho=0.727$ $p<0.05$), tangled nets ($\rho=0.717$ $p<0.05$) and plastic cups ($\rho=0.706$ $p<0.05$) showed significant correlation.

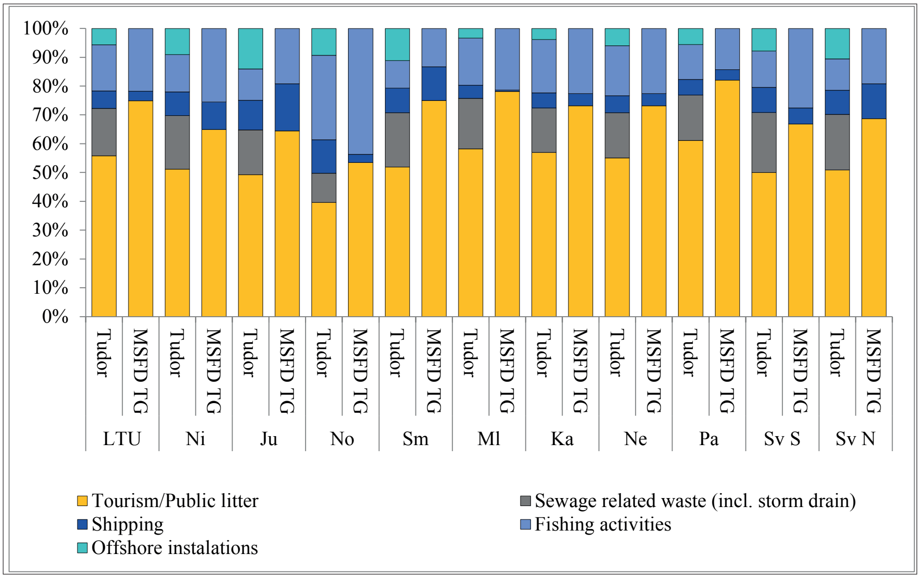

Figure 22. Sources of observed beach macro-litter in Lithuanian coast. Abbreviations: LTU – entire Lithuanian coast, Ni – the Nida, Ju – the Juodkrante, No – the NordBalt, Sm – the Smiltyne, Ml – the Klaipeda/Melnrage, Ka – the Karkle, Ne – the Nemirseta, Pa – the Palanga, Sv S – the Sventoji (South), Sv N – the Sventoji (North), Tudor – relates to the adapted Tudor matrix method, MSFD TG – relates to indicator items method.
22 pav. Lietuvos Baltijos jūros palūdimius teršiančių šiukšlių šaltiniai. Sutrumpinimai: LTU – visas Lietuvos krantas, Ni – Nida, Ju – Juodkrantė, No – NordBalt, Sm – Smiltynė, Ml – Klaipėda/Melnragė, Ka- Karklė, Ne – Nemirseta, Pa – palanga, Sv S – Šventoji (Pietūs), Sv N – Šventoji (Šiaurė), Tudor – pritaikytas Matricinio vertinimo metodas, MSFD TG – pritaikytas Indikatorinių daiktų vertinimo metodas.

4.4. Sources of beached marine litter

All the marine litter items found during the surveys were used for the potential pollution source determinations analysis, presented in this chapter. Figure 22 shows that tourism related (public litter) were the most common items on the Lithuanian beaches and contributed to 55.8 %, according to the Tudor matrix Scoring technique, and 74.9 %, according to the MSFD TG Marine litter categorization. The Palanga survey site had the highest amounts (61.1 % and 82.0 %) of Tourist related beached marine litter. The Curonian Spit revealed to have less influence from the tourism related pollution, as lower ratio, of items associated to tourism pollution source, was collected in the Curonian Spit beaches. On the contrary, to the Curonian Spit, the mainland beaches were mostly polluted by tourism related litter. However, the significance of shipping and fishing related items was greater in the Curonian Spit beaches. Despite the dominance of tourism related items the NordBalt survey site revealed to have the highest percentage of fishing related items among surveyed beaches.

Table 11. **Spearman rank correlations (ρ) between aggregated exposure to marine litter pollution parameters of different origin and related pollution sources (N=10).**

11 lentelė. **Spearmano ranginės koreliacijos (ρ) vertės tarp kranto savybių kaupti jūrą teršiančias šiukšles ir taršos šiukšlėmis šaltinių (N=10).**

	Spearman Rank correlation (ρ) with cumulative value of anthropogenic pressure to coast parameters						
	Tudor T	**MSFD TG T**	**Tudor Sh**	**MSFD TG Sh**	**Tudor Fi**	**MSFD TG Fi**	**Tudor Se**
ρ	.707*	.817**	-.585	-.511	-.043	-.352	.122
Sig.	.022	.004	.075	.131	.907	.319	.737
Spearman Rank correlation (ρ) with cumulative value of natural factors to coast							
	Tudor T	**MSFD TG T**	**Tudor Sh**	**MSFD TG Sh**	**Tudor Fi**	**MSFD TG Fi**	**Tudor Se**
ρ	.370	.211	-.426	-.737*	.722*	.155	-.753*
Sig.	.292	.559	.220	.015	.018	.669	.012

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed). Abbreviations: Tudor – relates to the adapted Tudor matrix method, MSFD TG – relates to indicator items method, T – Touristic/Public source, Sh – Shipping related source, Fi- fishing related source, Se – sewage related source.

The related pollution source and the aggregated exposure parameters of different origin for a coastal cell are presented in Table 11. The Tourism/Public related source after Schernewski et al. (2016) (ρ=0.707 $p<0.05$) and MSFD TG marine litter (Veiga J.M., et al. 2016) (ρ=0.817 $p<0.01$) relative pollution source allocation revealed to have the very strong positive Spearman rank correlations with a cumulative value of anthropogenic pressure to coast parameters. No other relative pollution source showed any significant correlations to the cumulative value of an anthropogenic pressure to coast parameters.

The Spearman Rank correlation between aggregated exposure parameters of natural origin and the relative pollution sources revealed to have diverse results. The MSFD TG marine litter proposed method indicated a statistically significant strong negative (ρ= -0.737 $p<0.05$) correlation between the shipping related source and the cumulative value of an anthropogenic pressure to coast parameters, while the Tudor matrix method was statistically not significant (ρ= -0.426 $p>0.05$). The sewage related source had a statistically significant strong negative (ρ= -0.753 $p<0.05$) correlation. The fishing related source, according to the Tudor matrix method, had a statistically significant strong positive (ρ= 0.722 $p<0.05$) correlation to a cumulative value of natural factors to the coast, while the MSFD TG marine litter fishing source allocation did not show any statistically significant correlation.

5

Discussion

One of the key challenges for the EU member states while implementing the MSFD is to determine what is “Good Environmental Status” (GES). Whilst the term is defined in the Directive (Article 3(5) MSFD), GES will have different meanings in the EU marine regions or the sub regions, and is therefore open to interpretation (Barnes and Metcalf, 2010). When dealing with the marine litter, more than one indicator will be required to assess the GES. This is determined by the complexity of the coastal and the marine environments, the character and the sources of the pollution. Therefore, a wide range of data is required while defining the baseline for each the GES indicator and specifically when evaluating Descriptor 10. While some EU Sea regions (e.g. the North-East Atlantic and the North Sea) may have regular and unified marine litter data lines ranging from 2001 (Schulz et al., 2013), others (e.g. Baltic Sea) just started monitoring of the marine litter (MARLIN, 2013). According to Barnes and Metcalf (2010) and the TSG ML (2015), use categories (fishery, recreation, household, etc.) provide the most valuable information for setting targets and reduction measures.

It would not be reasonable to argue that the marine litter would have an ultimate goal other than zero amounts in the marine environment. Based on the research in other EU Sea Regions (Schulz et al., 2013, CIESM 2014) and this study, it is clear that characteristics of the marine litter differ in different parts of the marine environment. Therefore, the targets of achieving GES need to be set by the EU member states on the basis of their national, the initial level of pollution within the area, consideration. Moreover, any assessment of the marine litter should consider the short-term variations caused by the meteorological and/or hydrodynamic events and the seasonal fluctuations, which could influence ability to detect underlying trends. The amount of litter present in the different marine environments is, amongst other things, dependent on the regional topography, including the seabed topography and the prevailing currents, winds and tidal cycles.

5.1. Distribution patterns, characteristics of marine litter and possible sources

5.1.1 Seasonal and spatial variation of beached marine litter

The seasonal variation in the amounts of marine litter is closely linked to the recreational activities and the tourism intensity at the coast. The waste generated at the coastal areas tends to increase during the touristic season (Ariza E. et al., 2008). This would explain the increase in the marine litter amounts during the warmer periods of the year. The seasonal variation, when talking about littering, is not only the tourism intensity, but also the frequency and the strength of the storm events, the pattern of the currents and the wind. The current study (the coast exposure exercise) showed that the natural forces are much more important when talking about a litter accumulation. It is rather obvious that during the high season of tourism the weather is usually calm and strong storms are not so frequent. Therefore, tourism related pollution will be most abundant during summer period. However, it is important to mention, that at the same time beach cleanings (the pollution prevention measures) are most often. It was recorded, that the local authority beach cleaning regimes influence the amount of litter found on the beaches (Velander and Mocogni, 1998, Moore et al., 2001, Somerville et al., 2003,). On the other hand, the results of increased beached litter pollution during the touristic season showed that measures taken may be not sufficient.

The shift from warm, calm summer season to more rough and stormy time of a year is equally important. During this time, beach cleaning become less frequent, resulting in the higher possibilities for litter at the beach migrate between the coastal and the marine environments. One of the mechanisms of such migration could be the rip currents. It was recorded that the rip currents are often sustained over sufficient temporal periods (hours–days) and the mean velocities (often > 0.5 m/s) enable a transport of large volumes of sediment offshore, particularly during the storm events (e.g. Thornton et al., 2007; Loureiro et al., 2012, Castelle et al., 2015).

The highest amounts of beached litter in autumn and lowest in winter and spring suggest that litter are washed ashore independent from the season. The pollution mitigation measures, such as beach cleanings and higher density of waste bins, have a short term influence on the level of beach pollution. However, the evidence of the highest amounts of beached marine litter during autumn does demonstrate a need for the more frequent, a full year beach cleaning campaigns or a necessity of beach cleaning after strong storms.

The weak positive correlation between the season when sampling was carried out and the amount of the litter indicates that the coast pollution with litter in the Lithuania is affected by the seasonal variation. However, the variation of the collected litter amount is rather high. This may somehow misrepresent the true range of the litter pollution over the different seasons.

The high spatial variation of the beached marine litter in the Lithuanian coast revealed the importance of proper selection of a sampling location. This may strongly determine the results of an assessment of marine pollution levels. The same pattern of a high spatial variation is also presented on the country level. According to the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) (2015) a mean amount of BML on a country level varies from 25 items/100 m in Italy to 1993 items/100 m in Croatia.

The macro-litter surveys tend to focus on the bulk sampling (items/100 m) (TSG ML, 2015). The coast pollution with the BML in Lithuania (mean of 167.4 items/100 m) is much lower than in SW Black sea (2400 items/100 m) (Galgani at al., 2015), similar to Greece (178 items/100m) or Egypt (122 items/100 m) (UNEP/MAP, 2015) but higher than in neighbouring Baltic Sea countries (~130 items/100 m according to MARLIN, 2013). However, the comparison of the density of beached marine litter in different beaches of the Lithuania provides with different understanding on the level of beach pollution, especially if compared with results in other countries worldwide. Therefore the Lithuanian BML density (0.028 items/ m^2) would be significantly lower compared to the Mediterranean Sea region (approx. 1/ m^2) (CIESM, 2014), the Black Sea (0.88 items/m^2) and the extreme values in Papua New Guinea (15.3 items/m^2) (Galgani at. al., 2015).

The recorded high variation of collected BML amount suggests that a judgment on the level of marine litter pollution may be uncertain. The criteria and methodological standards suggested by the Commission (2017/848/EC) tend to focus on the broader area for the GES evaluation. The proposal is to determine the trend based thresholds for the regional and the sub regional levels. However, even on the regional and sub regional level high variation still exists. This was evident from HELCOM (2017) report, where beached marine litter amounts varied from approx. 10 items/100m in the Western Gotland basin, up to approx. 160 items/100m in the Gulf of Riga or The Sound.

After analysing results of this study it is evident that the mainland coast and especially areas closer to the Klaipeda straight are more polluted with beached marine litter. This is recorded despite the fact that beach cleanings are officially carried out in Klaipeda city public beaches. A same tendency of higher BML amounts per linear meter and square meter was recorded closer to the Klaipeda harbour and larger settlement. The Karkle beach survey site (peri-urban and not cleaned) had the highest BML densities therefore proving the impact of beach cleanings may have on the results. On the other hand, the larger fraction beach sediment and presence of boulders could serve as a natural litter trap or a catcher (after strong storm). This was described in Moore et al. (2001) research, where remote rocky shoreline displayed higher densities of the marine litter, compared to the high-use sandy beach.

The progressive fragmentation of larger marine litter items in the marine environment is described by Thompson et al. (2004) and the upper size limit (5mm) for micro-litter is set (Arthur et al., 2009, TSG ML, 2015). The visual characterization is the most commonly used method for the identification of microplastics (Hidalgo-Ruz et al., 2012). The micro-particles in the size range, also used in this study (> 2mm diameter), are easily recognizable (TSG ML, 2015). The ability to visually distinguish artificial fragments from other natural and man-made particulates becomes increasingly difficult as the size of the particles under the examination decreases. This requires equipment (e.g FT-IR or Raman spectroscopy) that may be considered relatively costly compared to the sampling of large items of debris. In addition, the level of sample contamination increases when analysing smaller fractions of the marine litter. The implementation of the cost effective monitoring methods for large mirco-litter on a regular basis could provide lacking information for an initial status of pollution assessment and a baseline establishment.

The manual beach cleanings and the higher number of beach goers may have influence on variation of the macro-litter particles amount. Except, areas where the mechanical beach screening takes place, litter of a smaller fraction is not affected by the manual beach cleanings. Since there is no mechanical beach screening done in Lithuania, the implementation of micro-litter survey methods for the large micro- and meso-litter (Haseler et al., 2016) could provide additional information for objective beach pollution with marine litter assessment.

In terms of the seafloor pollution by marine litter, the Lithuanian marine area is not an exception. The marine litter items observed at the sea floor are also present in other EU Sea regions or oceans. The marine litter on the seafloor were found on the seabed of all seas and oceans and the presence of large amounts were reported (Galgani et al., 2000; Barnes et al., 2009). The large-scale evaluations of seabed debris distribution and densities were present at the global (Galgani et al., 2000) and the regional levels (CIESM, 2014).

According to the research carried out by Galgani et al. (2000) a mean concentration of the SML in the Baltic Sea regions was 82 items per km^2. The same research revealed that the SML may vary from 5.8 items per km^2 (Bay of Seine) to 251 items/km^2 (Adriatic Sea). This high variation in the SML densities across the European seas demonstrate that unified baseline on the SML currently is not possible. The densities of the SML in the Lithuanian marine area also showed great variability between geomorphologic regions and even within the same region. When compared to densities recorded in the Baltic Sea it is evident that 111.6 items/km^2 is slightly above a regional value.

The highest densities of the SML in Lithuania were recorded in areas over 30 km away from the Klaipeda straight. The distance and a fact that prevailing bottom currents are north oriented (Ferrarin and Umgiesser, 2013) suggests that the Nemunas river discharge via the Klaipeda straight is not influencing the SML accumulation in the Lithuanian marine area.

The changing speed of currents in deeper areas of the Bay of Biscay or the Mediterranean Sea resulted in an originated confinement sites for the marine litter (Galgani et al., 2000). The similar pattern was observed in the Lithuanian marine area, where the SML accumulation zones were located in areas of a rapid change of the bottom current speed. The accumulation zone in the Palleovalley of Nemunas River was located in an area where, according to Ferrarin and Umgiesser (2013), the bottom current slows down (from 5 cm/s to close to 0 cm/s). Whereas the accumulation zones on the slopes of Gdansk basin were located in the areas of increase of the bottom current speeds (from close to 0 cm/s to 5 cm/s).

The location of the SML accumulation zones is also influenced by the human activity factor (Galgani et al., 2000). The highest quantities of the SML in the Lithuanian Exclusive Economic Zone (EEZ) were recorded on the direct shipping routes or in a close proximity of the most intensive ship passage ways. It indicates that vessels going in and out the Klaipeda harbour and across the Lithuanian EEZ may be considered as direct source of the SML. It also indicates the failure to comply with MARPOL 73/78 Convention annex V and HELCOM Convention IV rules.

5.1.2 Marine litter items, material type and source determination

It was observed, that the cigarette butts contribution to the overall pollution was around 13 % of all the artificial polymer types and resulted in the second most common item in all survey sites. The high abundancies of cigarette butts were recorded all over the globe (GRID-Arendal, 2016). The most common items, constituting over 80 % of the litter stranded on beaches were cigarette butts, bags, remains of fishing gear, and food and beverage containers (Andrady, 2015). The use of identification and reporting of collected/observed marine litter as a basis for the source assessment is widely used (Tudor et al., 2004, Veiga et al., 2016). The visual survey methods provides a good overlook of the state of art of the coast pollution with marine litter however due to the item fragmentation the items definition becomes more difficult. This factor is important when trying to determine the possible pollution source.

The source determination based on the collected/observed marine litter items is possible when litter items are sufficiently intact. The choice of preferred source allocation method may influence the significance of different pollution source, however main tendencies will still remain. This was demonstrated by applying matric scoring technique (Tudor et al., 2004) and indicator items based relative pollution source determination methods(Veiga et al., 2016). Despite the differences in source allocation both methods (the Matrix scoring technique and the Indicator item) revealed that tourism or beach goers contribute the most to the marine litter pollution in the Lithuanian coast. This proved that, if applied with caution, both methods can provide a preliminary indication on the most important pollution sources.

The determination of marine litter pollution source is a key step while developing the pollution prevention measures. Once the pollution source is identified, a detailed analysis of the litter pathways may help in monitoring effectiveness or implementing the new measures. This was evident in decrease in amount of plastic bottles (source – tourism/public) after Lithuanian government implemented the deposit system (from February 2016) for the plastic beverage bottles. This example also illustrates that, measures implemented on higher levels of litter supply chain, resulted in a significant reduction of pollution on a national level.

5.2. Importance of coast characteristics in beached marine litter monitoring

Development and application of coast monitoring and litter characterization methods allows better understand the influence of the dynamics of the marine and the coastal environment. This also contributes while predicting the future scenarios, better understanding of importance of different environmental components when assessing the pollution level and applying the mitigation measures.

This study showed that the coast exposure to marine litter evaluation provides more robust and predictive overview of the marine pollution pattern and the level. The coast exposure to marine litter pollution assessment integrated an anthropogenic pressure to the coast and the natural factors.

The contribution to the overall pollution level by the larger settlements (especially Klaipeda city) was presented in this study. For instance the small settlements of the Curonian Spit are located on the Curonian Lagoon side (sometimes over 2.5 km away from the Baltic Sea) with well-expressed pathways towards the sea. At the same time main coast settlements are located on the Baltic Sea coast and beach accessibility remains more constant throughout the entire coast. Due to the close proximity of Klaipeda city urbanization caused pressure is much higher on the mainland coast.

The pollution prevention measures, such as beach cleanings and waste management infrastructure (trash bins, waste containers) do have an impact on an overall cleanliness of the coast. However, the same factors may have an opposite result if maintenance of the infrastructure is not executed daily. This was clearly illustrated while observing the litter accumulation pattern around the trash bins on the beach.

Marine litter is a result of the anthropogenic activities; however once in the marine environment it obeys rules and laws of nature. Therefore the forces of nature govern the fate of items in the marine environment. The Baltic Sea shows properties that differ significantly from the North Sea/Atlantic region. It is an inland sea with very limited water exchange with other sea regions. It has a ragged very long coastline compared to the sea surface area. On the northern coast in Scandinavia, an isostatic uplift of land is observed. Consequently, rocky coasts dominate and beaches, that fulfil the OSPAR criteria for a suitable monitoring beach, are rare. Along the southern Baltic coast, many beaches exist that are used for recreational purposes and regular beach cleanings are common during summer season. The major pollution sources for beach litter are beach visitors and urban areas. Since other sources play only a minor role and offshore introduced litter will end-up on the coast within days and weeks (Schernewski et al., 2016). Due to these circumstances, once marine litter enters the Baltic Sea it can circulate and fragment in the water column, sink to the seafloor or can be deposited on the beach. Since previous studies show that greatest amounts of marine litter are observed ashore it can be assumed that Baltic Sea coast is a marine litter sink area.

5.3. Marine litter socio-economic pressures in Lithuania

From a socio-economic perspective, marine litter reduce the recreational, aesthetic or educational value of an area. It also may cause direct costs and loss of income in a range of maritime sectors such as fisheries, shipping and leisure boating. Levels ofeconomic "harm" may run into millions of euro annually even at the sub-regionalscale (Mouat et al., 2010). Furthermore, sanitary, sewage-related and medical wastemay cause injuries and/or be a risk to human health (Ivar do Sul and Costa, 2007).

The marine litter does put a financial pressure on the coastal municipalities in Lithuania. Based on the discussions with the local waste management companies and municipality representatives it is estimated that around 590 000 euros are needed annually for the beach cleanings of the official bathing sites (approx. 49 km of Lithuanian Baltic Sea coast). The macro-litter beach monitoring generates considerable labour related costs. Other costs like the laboratory analyses, equipment or shipping are negligible. JRC (2013) estimates the annual effort for running a monitoring at 4 beaches including all other costs, like data analysis and reporting to 55 person days. Taking into account, that the suggested beached marine litter monitoring in Lithuania includes sampling of macro-, meso- and micro-litter in 4 beaches, an estimated total costs of 48 person-days are well in rage.

5.4. Recommendations for beached marine litter monitoring in Lithuania

The beach macro-litter monitoring is a well-established methodology, was successfully applied in the North Sea/Atlantic region (OSPAR convention area) and it is supposed to become a European-wide methodology within the MSFD.

The establishment of representable monitoring sites and methods requires careful consideration of natural and anthropogenic characteristics of the coast. However, such approach is still being developed as majority of EU countries are still discussing proper marine litter survey methods and thresholds to be reached. As a first step in achieving and keeping the GES until 2020 TSG ML recommended a trend-based target establishment.

The beach cleanings, the limited emission of the litter on sea and lack of long distance transport from oceans are responsible for the relatively low numbers of beach litter in the Baltic Sea if compared to the other European Sea regions or the Atlantic Ocean (Schernewski et al., 2016, UNEP/MAP, 2015). Also taking into account high variability of beached and seafloor marine litter in the study area, as well as heterogeneity of the coast, commonly applied monitoring may not represent marine environment pollution levels in the Lithuanian coastal zone sufficiently.

Beaches free of human disturbances are rare, the coast framework conditions such as an exposition to wind, currents or pollution sources vary on a small spatial scale, and even remote beaches often show strong spatial gradients in the beach litter pollution (Schernewski et al., 2016). The dominance of west and south-west winds, coast orientation, along-coast transportation of the litter have to be taken into account when analysing the results of beached marine litter monitoring.

A beach monitoring for the macro-litter is being established all over the Europe, and the question is how this should look like at the Lithuanian coast? JCR (2013) recommends choosing beaches for survey in a way that they are subject to different litter exposures, namely urban coasts that reflect the contribution of land-based inputs; rural coasts that serve as background for litter pollution levels and coasts close to major rivers, to reflect the contribution of riverine input to coastal litter pollution.

The cluster analysis and pollution source analysis at the Lithuanian coast shows, that there is a possibility of defining one or several beaches that are representative (with respect to litter amounts and compositions) for a larger area. However, in terms of a certain pollution source, tourism/beach goers always remain dominant. An exposure to marine litter pollution approach revealed to have better coast differentiation abilities when it comes to pollution source contribution on to the coast sections differentiation. Therefore, this study data and statistical analysis may contribute to the monitoring strategy development and location of the monitoring stations.

The practical and cost-effectiveness aspects should to be taken into consideration. Schernewski et al. (2016) claimed that a monthly monitoring does not make sense, as it shows no significant change in the BML amount variability compared to the seasonal monitoring in the Baltic coast. Surveys done on a 4-time a year basis ensure seasonal representation and are comparable on a national and international levels. Based on results of this thesis, gained experience and coastal characteristic four beaches to be monitored should be sufficient in the Lithuanian coast.

A supplementary surveys on the smaller fraction (<2.5 cm in diameter) of beached marine litter can provide an objective results for beach pollution with litter assessment. The research in development and application potential of two smaller fraction BML survey methods (Frame- and rake-method) in this study provide sufficient information on method capabilities. Frame-method focuses on the survey of three different areas of the beach. Although such approach allows covering different natural factors, which influence marine litter accumulation, it also neglects the special distribution within the beach. The distance between the sampling areas may eliminate subjectivity of the method. However a small area sampled, compared to the Rake-method, and higher particle dispersion between the transects, within one sample, gives a hint to the lower level of representing beach pollution with marine litter level. On the other hand Rake-method focuses on the surveying entire width of the beach and methodology provide data on the spatial distribution of litter. This information may be valuable when analysing litter transport mechanism on the beach and in the marine environment.

Sampling time and precision are main factors which determine the differences between the Rake- and the Frame- methods. While Frame-method focuses on the smaller area, it emphasizes the precision of surface scoping and sieving. This was reflected by the slightly higher mean amount of particle found during this research. Using a rake scoping method it is not always possible to guarantee that 3 mm of the surface sand will be sieved. However larger survey area and close proximity of transects does compensate the lack in precision. This is emphasized by the significantly low sample dispersion. In the perfect sampling conditions (no wind and dry sand) Frame-method is more precise technique, however sampling time is faster for the Rake-method.

The importance of the weather conditions is very well represented with the Rake-method. The Frame-method utilizes water during the sieving of the sand while rake-method is based on the physical shaking of the sand-rake. If the beach sand is wet or it is raining Rake-method becomes nearly impossible due to the wet sand granules sticking together. In this case it is required to carry the sand-rake to the sea water and apply the Frame-method principles. This procedure not only is more physically demanding but also doubles the time it takes to sample one beach.

Since smaller fraction (large micro- and meso-litter) samplings revealed to have smaller variability in an amount, a complimentary surveys using Method No. 2 (sand rake) should be taken into consideration while implementing a national monitoring.

A further development of the national monitoring strategies are necessary in order to fully comply with the specifications and standardized methods for monitoring of marine litter, as stated in the Commission decision 2017/848/EU. Based on the results of this study and experiences gained following recommendations for beached marine litter monitoring in Lithuania are formulated:

- Beached marine litter should be monitored in 100 meter length transects. All identified items should be collected.
- The monitoring locations/sites should be accessible all year round. Monitoring should be based on a survey of the Nida-Juodkrante; the Curonian spit (the NordBalt cable Baltic Sea entrance beach); the Klaipeda-Karkle; the Nemirseta – Palanga coastal sections;
- Four surveys per year (spring, summer, autumn and winter) at each site are recommended. Monitoring site coordinates should be documented in order to ensure repetitive surveys are carried out at the same location;
- National monitoring (documentation and item characterization) has to follow the "Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area" developed by OSPAR Commission (2010). This will ensure compliance to Commission decision 2017/848/EU while classifying beached marine litter into the given standardized categories: artificial polymer materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics, chemicals, undefined, and food waste.
- Rake-method should be used as a supplementary methodology to commonly used macro-litter for smaller fraction marine litter monitoring. Combination of macro- and smaller fraction marine litter surveys would ensure implementation of JRC (2013) recommendations for marine litter monitoring.

6

Conclusions

1. Marine litter is abundant both on the beaches (litter was found in each survey) and on the seafloor (only 16 % of bottom trawling campaigns were litter free) of Lithuania. The artificial polymer material dominantes other type of marine litter (with the share of - 83 % on the coast and - 71 % on the seafloor).
2. Marine litter tends to accumulate in the depressions (areas of rapid shift of near bottom hydrodynamic conditions of the seafloor) such as the Palaeovalley of Nemunas River and the slopes of Gotland and Gdansk basins as well as in a close proximity of intensive ship traffic.
3. Marine litter pollution of the Lithuanian coast is highly variable on a spatial and temporal scale. The most polluted are beaches in a close proximity to the urbanized areas. The highest amount of marine litter was observed at the Klaipeda and the Karkle beaches (both on the mainland coast). Tourism/public related (up to 75 % of identified items on the coast) activities are the main pollution source of the litter at Klaipeda city beaches followed by the fishing related litter (up to 45%) which are more common for the Curronian Spit beaches;
4. Beach monitoring based on the large micro- and meso-litter proved to be more accurate while assessing the pollution level of sandy beaches. The complimentary statistical comparison of large micro- and meso-litter sampling methods

revealed that Rake-method is more reliable and accurate approach if compared with Frame-method to be used for the Lithuanian coast monitoring;

5. The ability to accumulate and the amount of the litter on the sandy beaches of Lithuania directly depends on the natural features of the coast and human induced pressures. The statistical relationship between exposure to marine litter pollution and the amount of beached marine litter is statistically significant and strong ($\rho=0.848$, $p<0.01$). The most exposed to the litter pollution are beaches close to the main settlements (Klaipeda and Palanga) – the Smiltyne, the Klaipeda, the Karkle and the Palanga beaches. But litter accumulation on the main part (~84 %) of the Lithuanian coast can be considered as very low to medium;
6. The national monitoring of the marine litter should be based on the coast abilities to accumulate the litter. The sites (beaches) for the monitoring should be selected according to the results of the coastal exposure assessment and the litter sampling needs to be supplemented with large micro- and meso-litter sampling (Rake-method) methods. It is recommended that 4 seasonal surveys should be carried each year at the 4 coastal sites – the Nida-Juodkrante; the NordBalt cable passage through the Curronian Spit; the Klaipeda-Karkle and the Nemirseta – Palanga.

7

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8

Annex

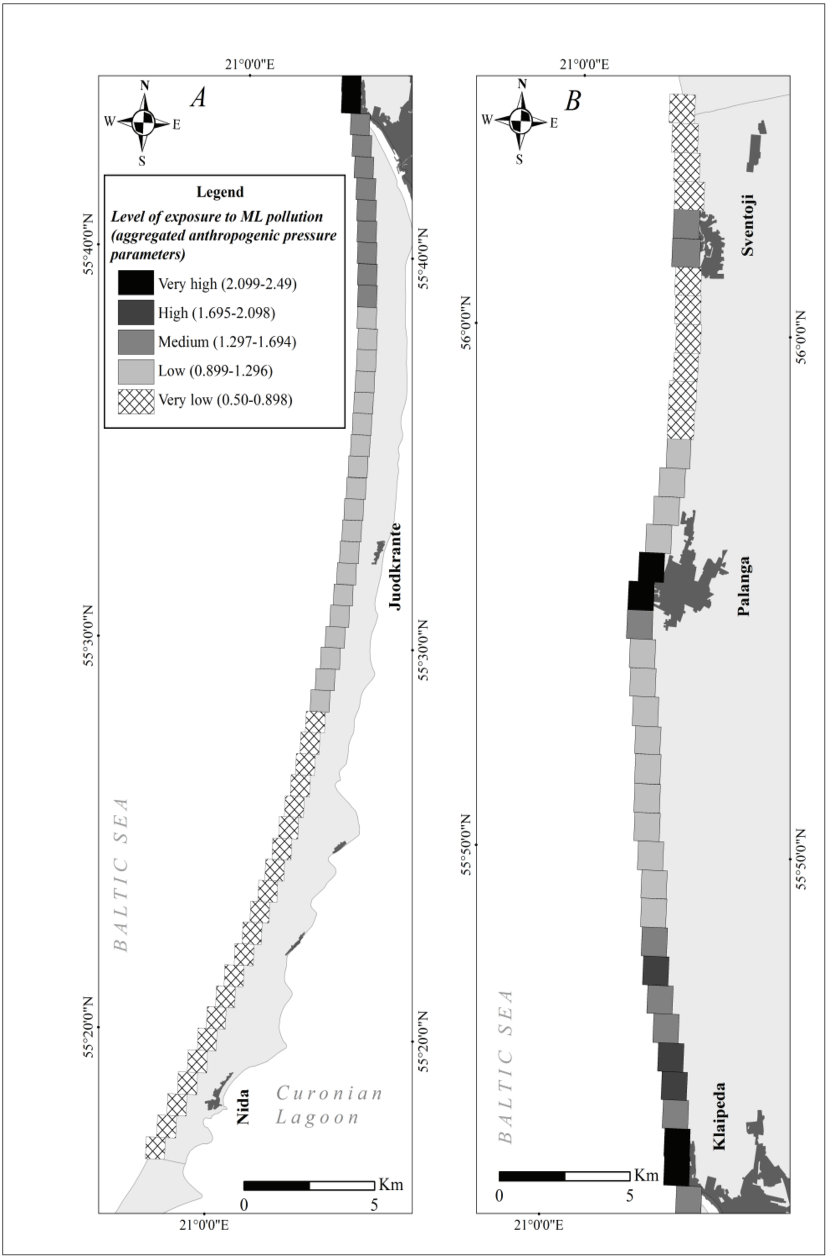

Figure A1. Level of coast exposure to marine litter pollution based on the aggregated rank values of anthropogenic parameters.

A1 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal suminę antropogeninės apkrovos aplinkai parametrų vertę.

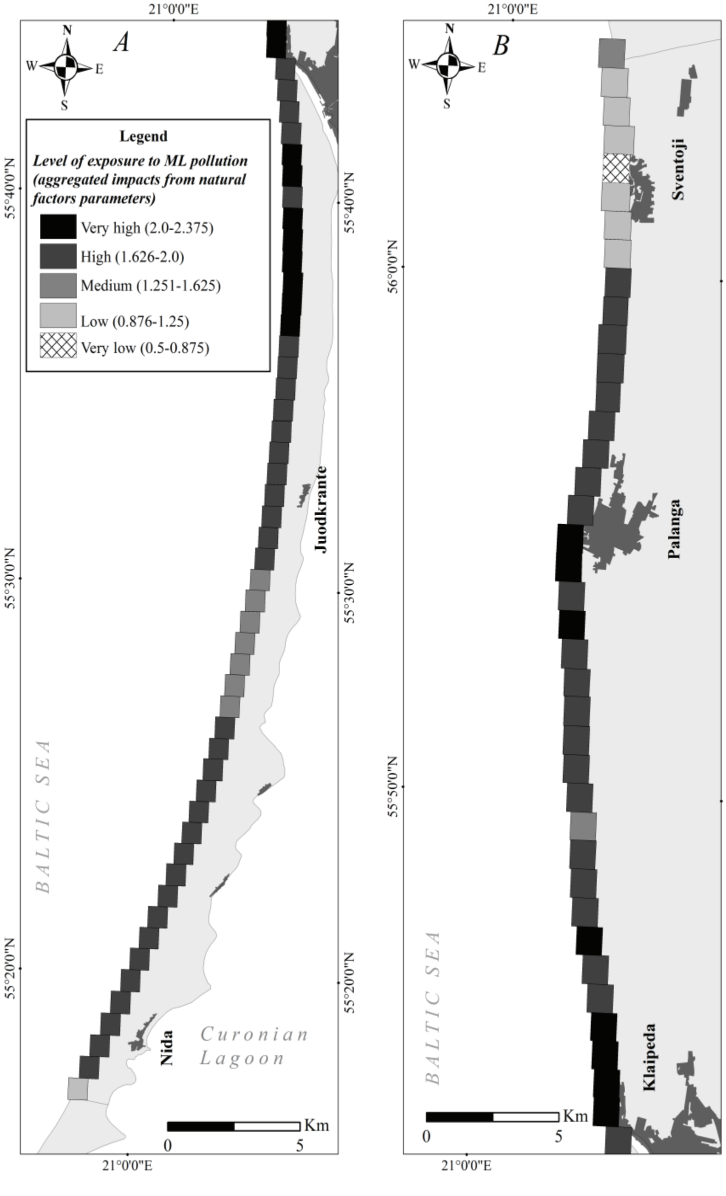

Figure A2. Level of coast exposure to marine litter pollution based on the aggregated rank values of impacts from natural factors parameters.

A2 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal suminę gamtinės kilmės faktorių vertę.

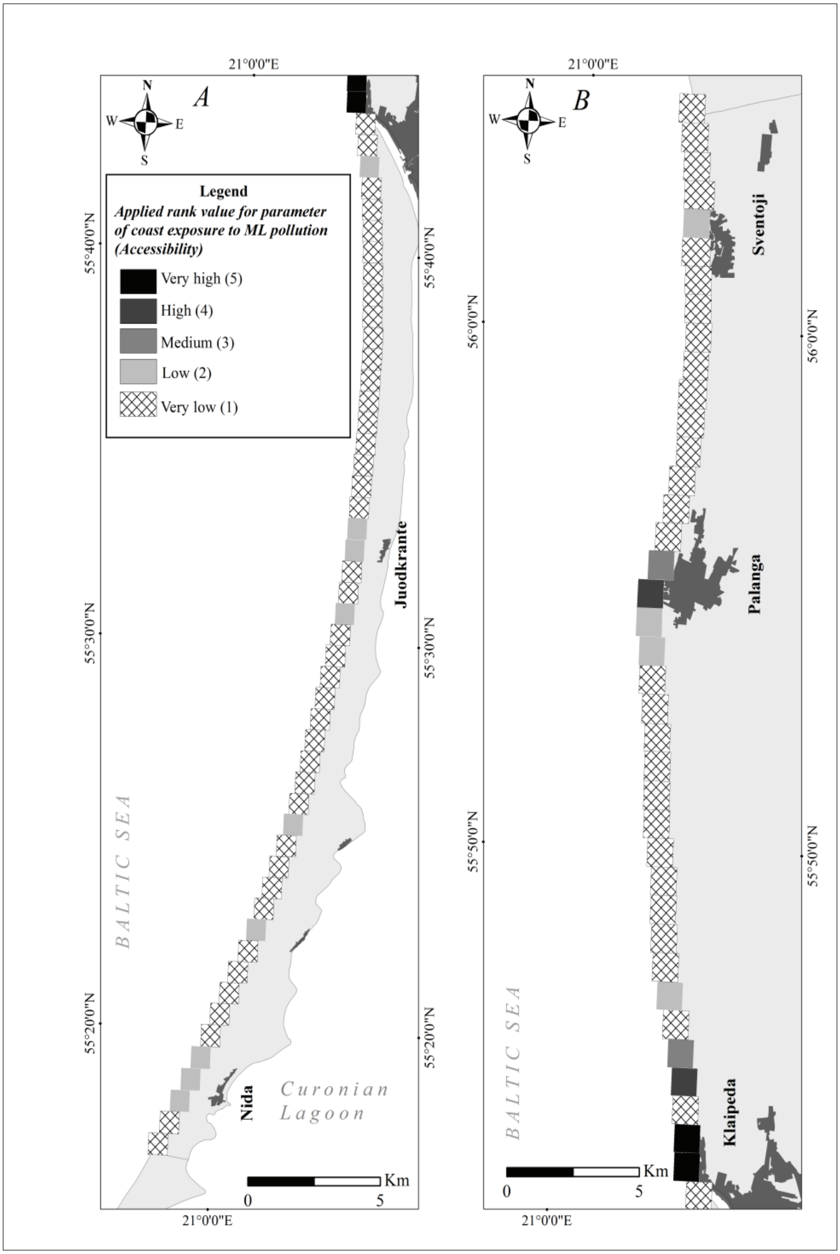

Figure A3. Level of coast exposure to marine litter pollution based on the rank values of coast accessibility.

A3 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal pakrantės pasiekiamumą.

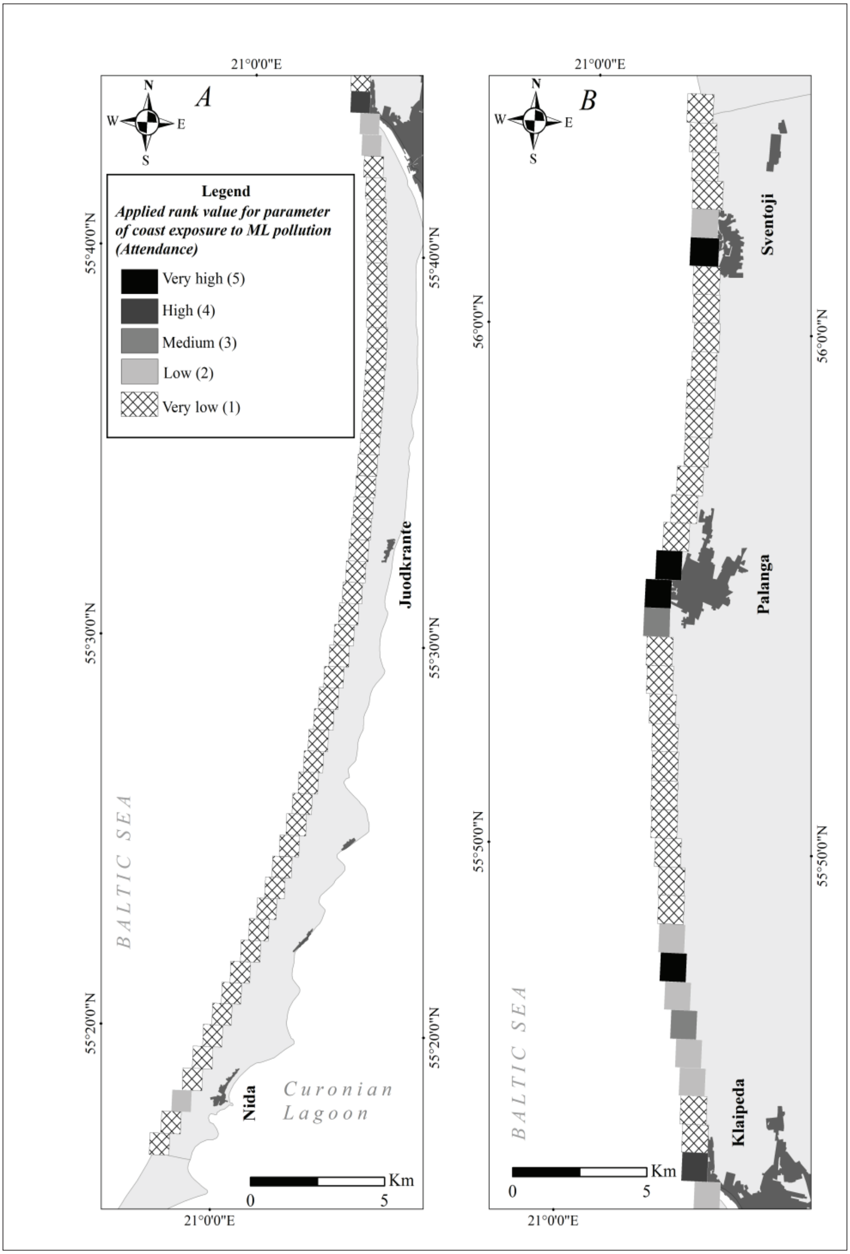

Figure A4. Level of coast exposure to marine litter pollution based on the rank values of coast attendance levels.

A4 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal pakrantės lankomumą.

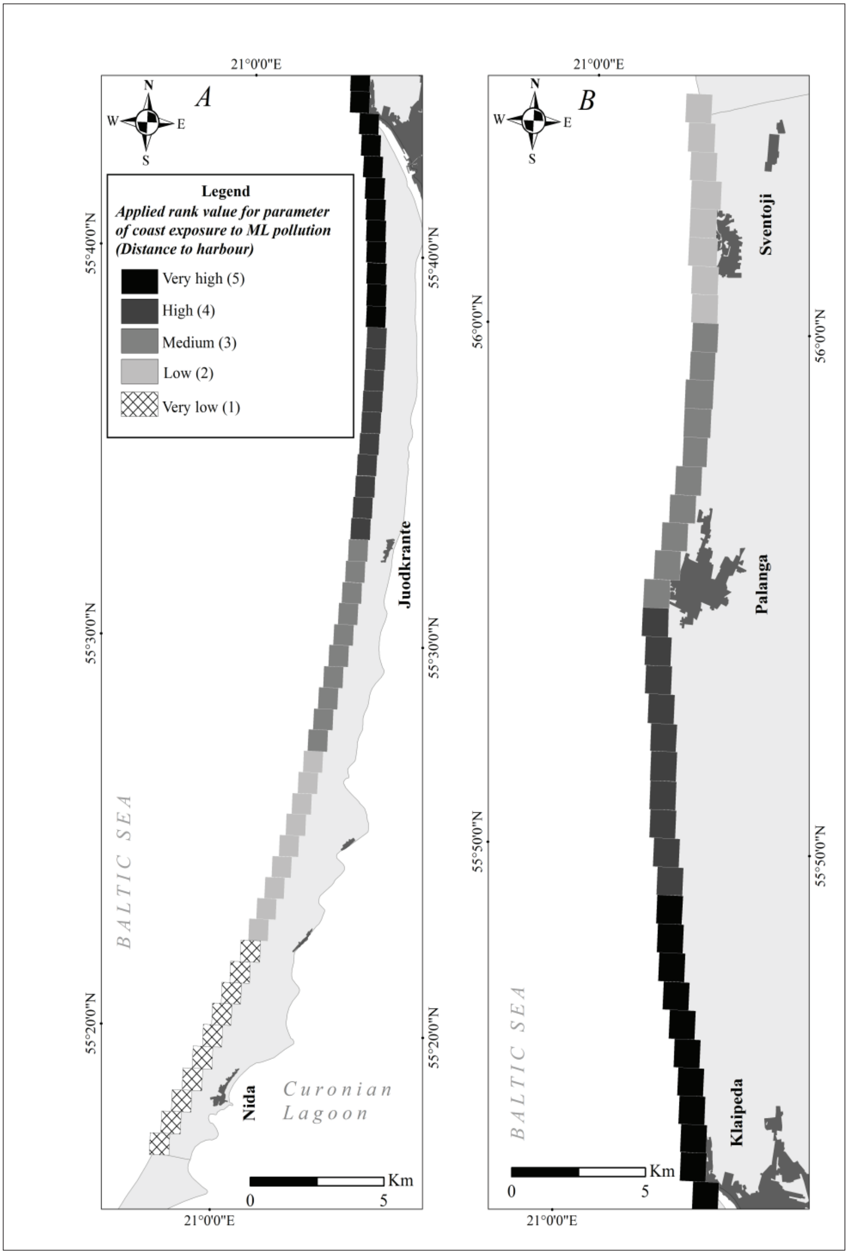

Figure A5. Level of coast exposure to marine litter pollution based on the rank values of distance to the harbour.

A5 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal atstumą iki Klaipėdos valstybinio jūrų uosto.

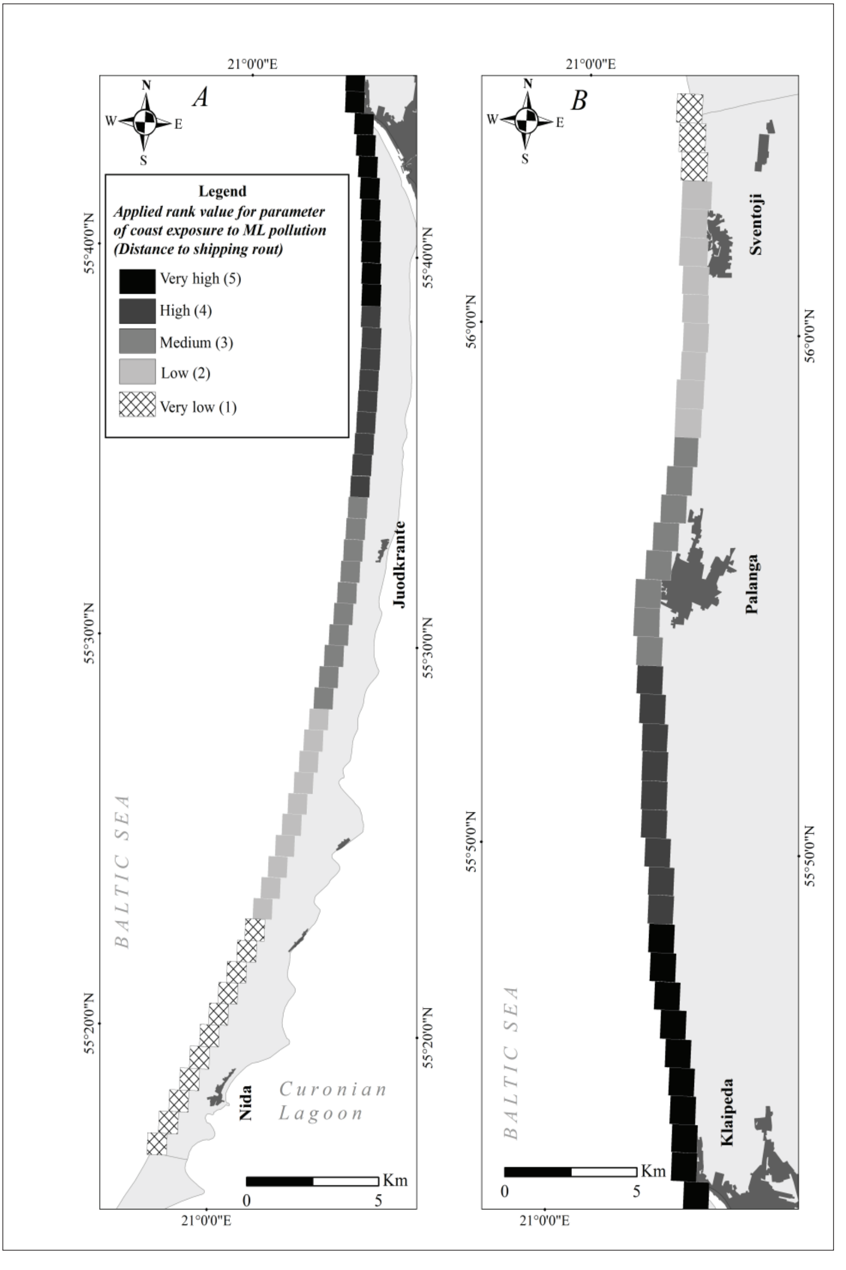

Figure A6. Level of coast exposure to marine litter pollution based on the rank values of distance to shipping routes.

A6 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal atstumą iki laivybos kelių.

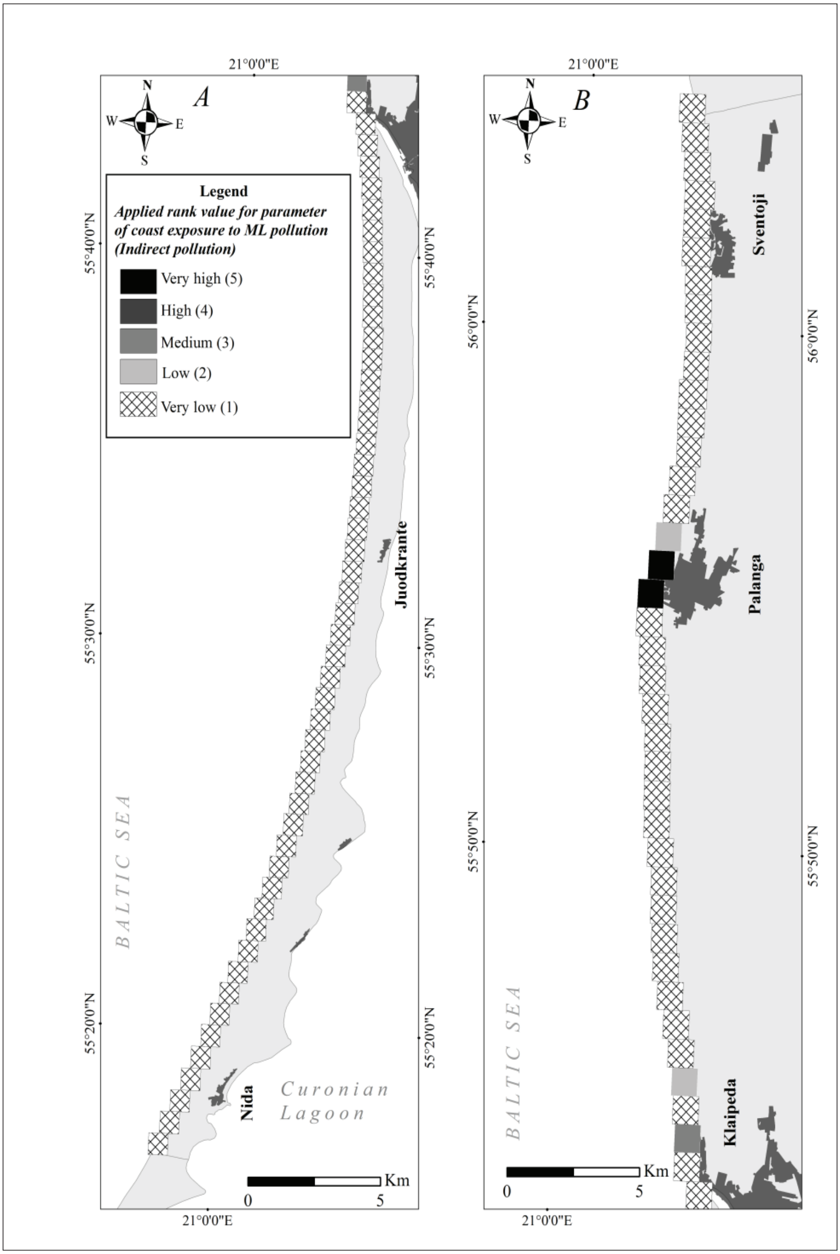

Figure A7. Level of coast exposure to marine litter pollution based on the rank values of indirect pollution parameter.

A7 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal netiesioginę taršą.

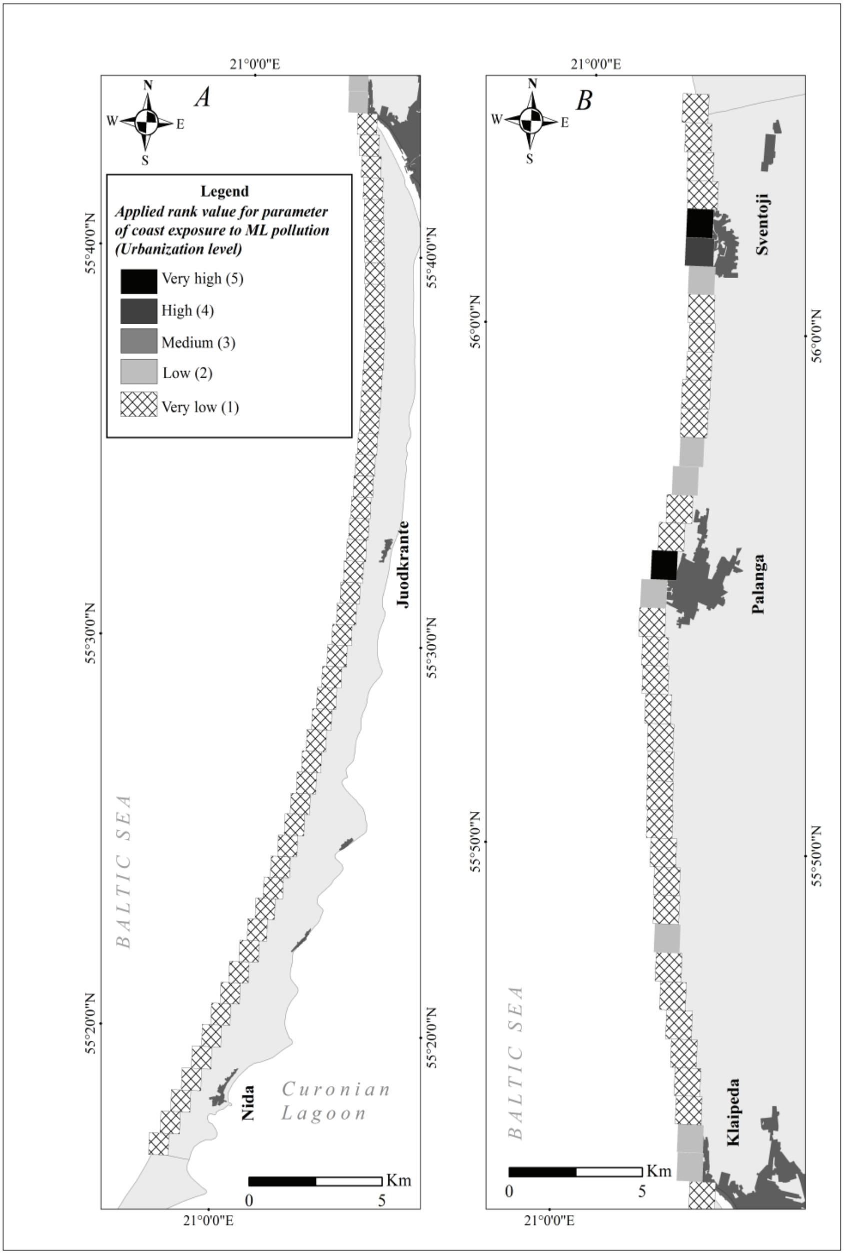

Figure A8. Level of coast exposure to marine litter pollution based on the rank values of level of urbanization parameter.

A8 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal urbanizacijos lygį.

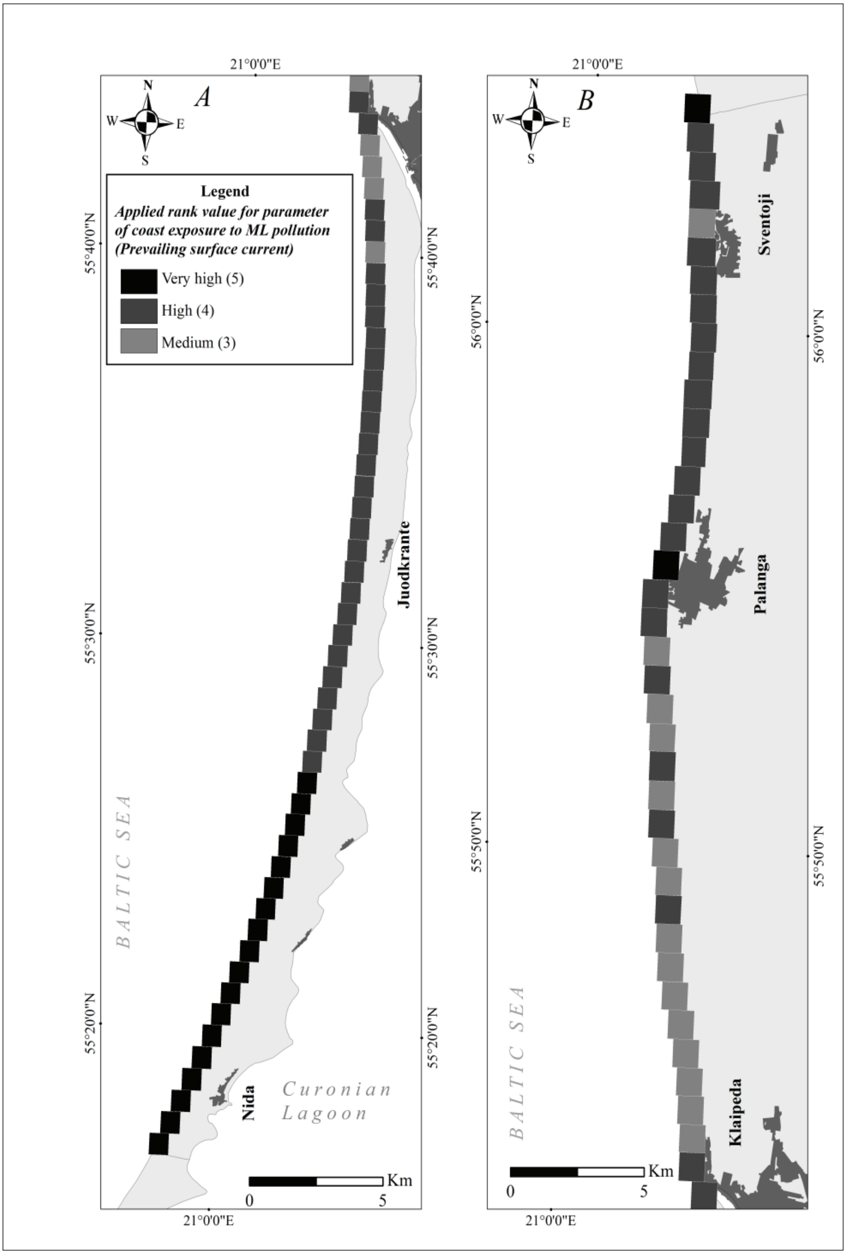

Figure A9. Level of coast exposure to marine litter pollution based on the rank values of prevailing surface current parameter.

A9 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal vyraujančią paviršinio vandens srovės kryptį.

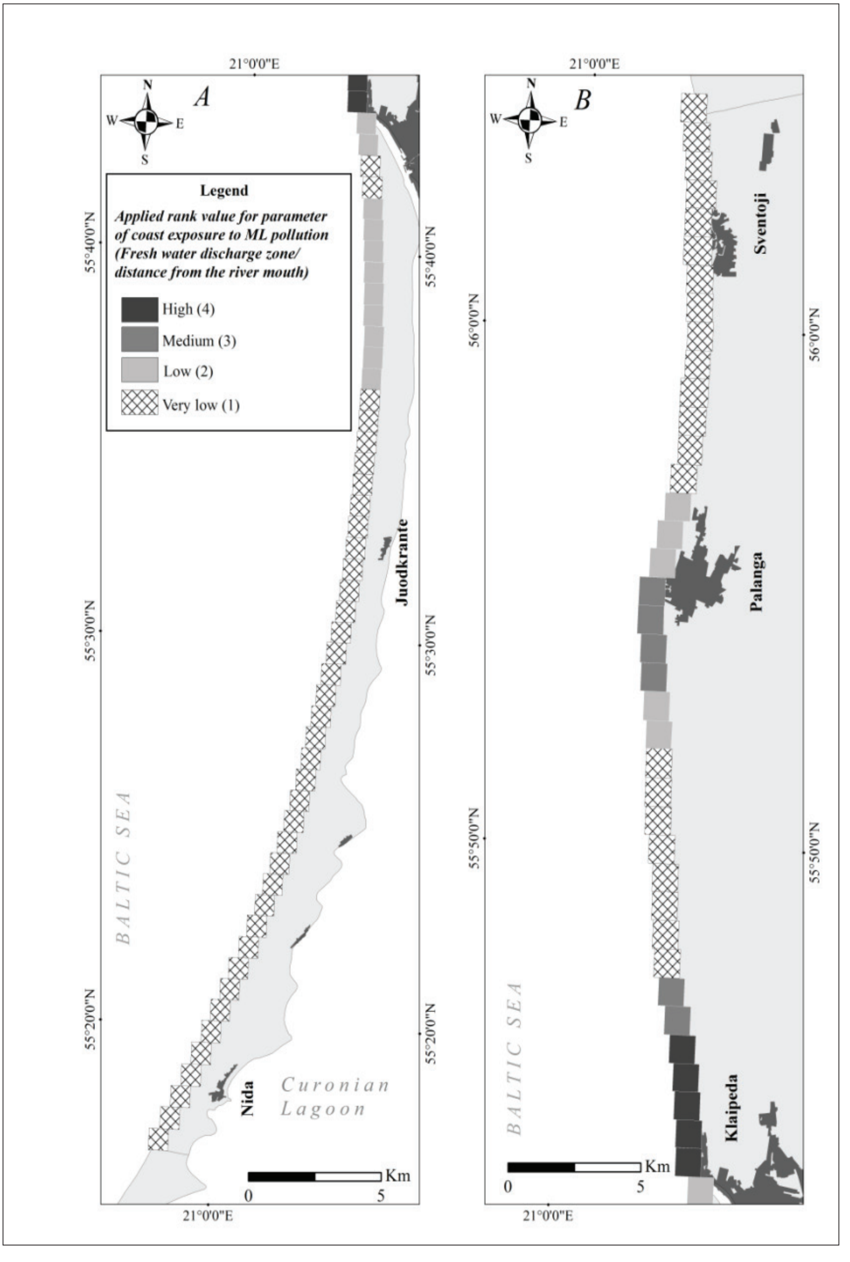

Figure A10. Level of coast exposure to marine litter pollution based on the rank values of fresh water discharge zone/distance from the river mouth parameter.

A10 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal gėlo vandens (pliumo) zoną/atstumą iki upės (šiuo atveju Klaipėdos sąsiaurio žiočių).

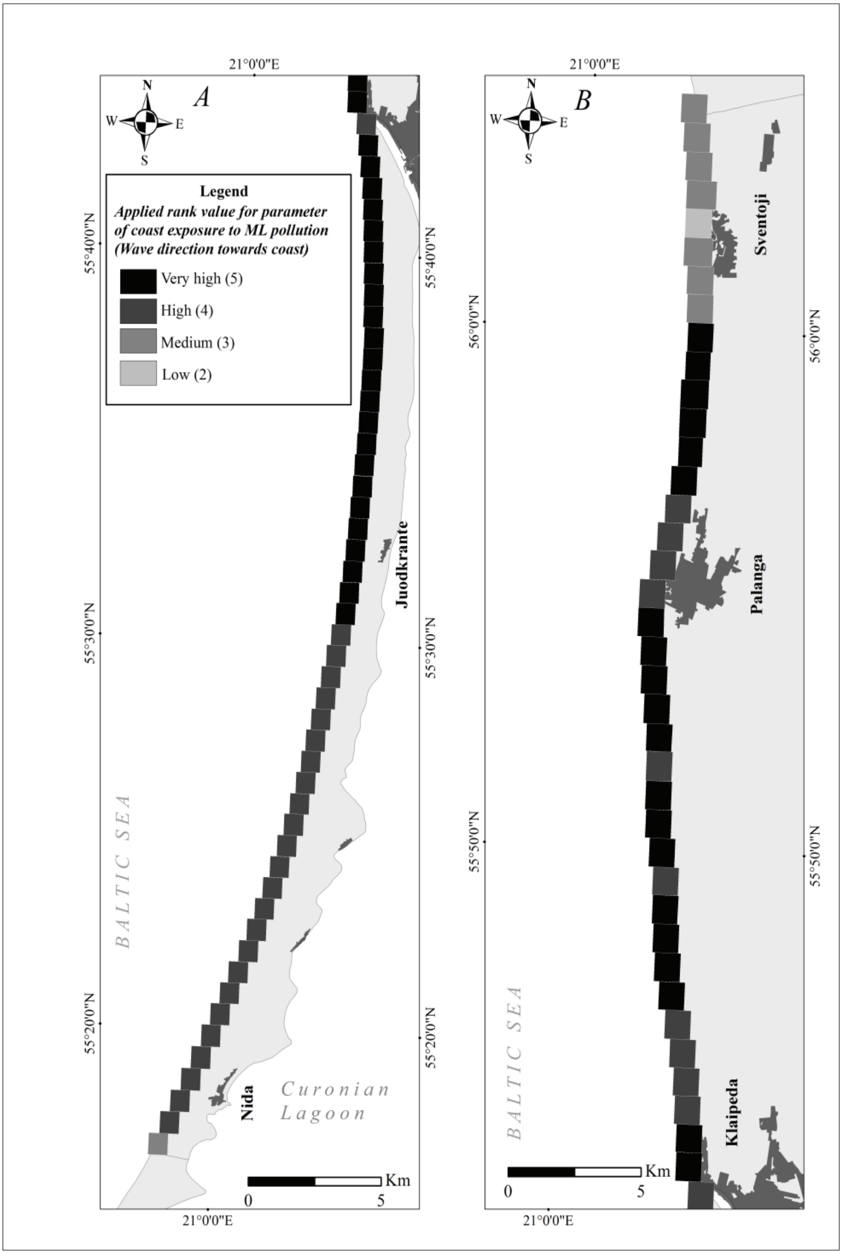

Figure A11. Level of coast exposure to marine litter pollution based on the rank values of wave direction towards coast parameter.

A11 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal vyraujančią bangos kryptį.

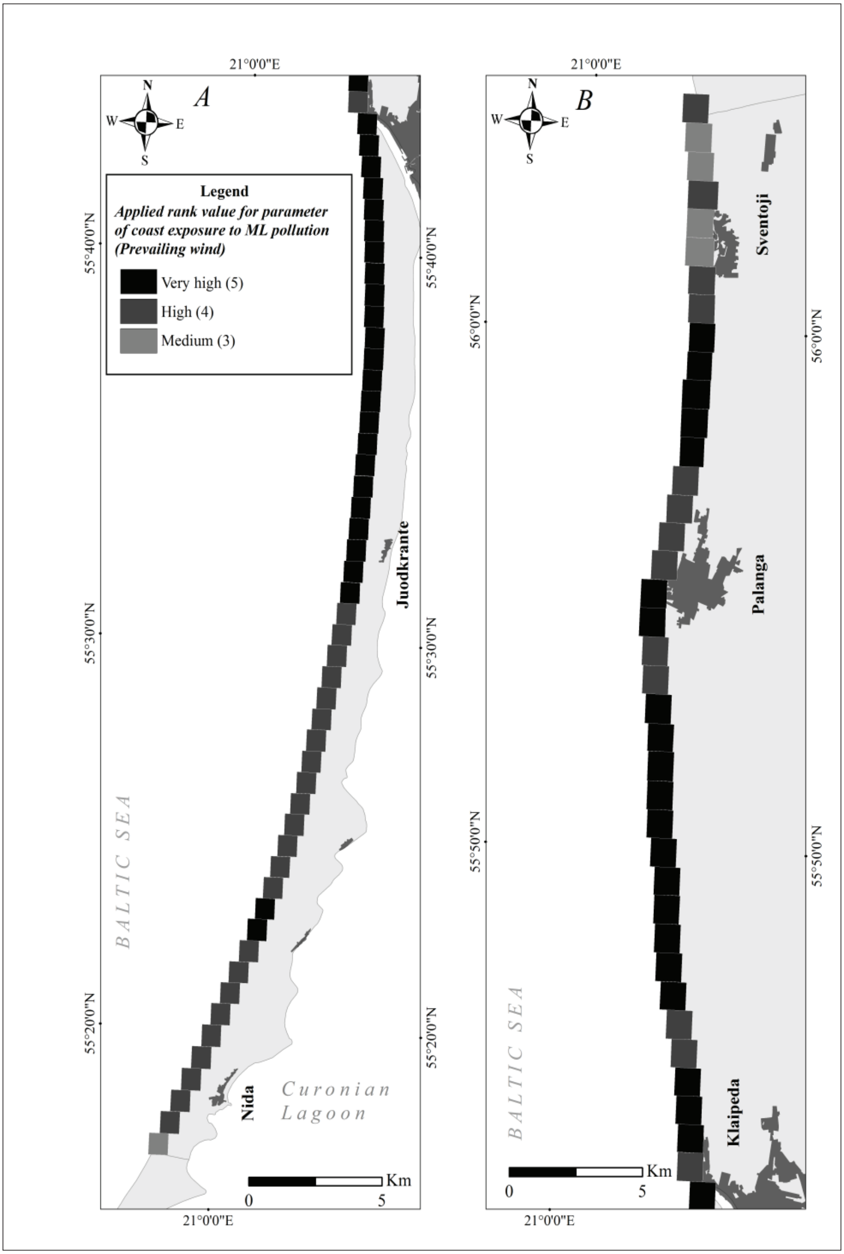

Figure A12. Level of coast exposure to marine litter pollution based on the rank values of wind direction towards coast parameter.

A12 Pav. Kranto savybių kaupti jūrą teršiančias šiukšles lygis vertinat pagal vyraujančią vėjo kryptį.

Table A1. **Results of beach similarity analysis, using mean amount of marine litter as an input parameter for t-test.**

A1 lentelė. **Paplūdimių užterštumo šiukšlėmis panašumo, naudojant vidutinį šiukšlių kiekį, analizės rezultatai.**

Survey site	Nida (N=4)	Juodkrante (N=4)	Nordbalt (N=4)	Smiltyne (N=4)	Klaipeda (N=16)	Karkle (N=14)	Nemirseta (N=16)	Palan-ga (N=16)	Sventoji S (N=4)	Sventoji N (N=4)
Nida (N=4)										
Juod-krante (N=4)	t(6)= 0.73, p=0.494									
Nordbalt (N=4)	t(6)= 3.10, p=0.021	t(6)= 1.56, p=0.169								
Smiltyne (N=4)	t(6)= 1.87, p=0.111	t(6)=1.12, p=0.305	t(6)= -0.07, p=0.948							
Klaipeda (N=16)	t(18)= 5.81, p<0.001	t(18)= 5.24, p<0.001	t(18)= 4.44, p<0.001	t(30)= 4.22, p=0.001						
Karkle (N=14)	t(16)= 4.00, p=0.001	t(16)= 3.37, p=0.004	t(16)= 2.43, p=0.027	t(16)= 2.23, p=0.04	t(28)= -3.46, p=0.002					
Nemirse-ta (N=16)	t(18)= 4.18, p=0.001	t(18)= 3.08, p=0.006	t(18)= 1.53, p=0.144	t(18)= 1.24, p=0.232	t(30)= -6.74, p<0.01	t(28)= -2.72, p=0.011				
Panalga (N=16)	t(18)= 2.27, p=0.036	t(18)= 1.61, p=0.125	t(18)= 0.47, p=0.644	t(18)= 0.38, p=0.708	t(30)= 6.63, p<0.001	t(28)= 3.01, p=0.005	t(30)= 0.91, p=0.368			

Survey site	Nida (N=4)	Juodkrante (N=4)	Nordbalt (N=4)	Smiltyne (N=4)	Klaipeda (N=16)	Karkle (N=14)	Nemirseta (N=16)	Palan-ga (N=16)	Sventoji S (N=4)	Sventoji N (N=4)
Sventoji S (N=4)	t(6)= -1.21, p=0.273	t(6)= -0.36, p=0.731	t(6)= 1.24, p=0.263	t(6)= 0.86, p=0.424	t(18)= 5.02, p<0.001	t(16)= 3.11, p=0.007	t(18)= 2.66, p=0.016	t(18)= 1.29, p=0.212		
Sventoji N (N=4)	t(6)= -0.83, p=0.437	t(6)= -0.06, p=0.956	t(6)= 1.59, p=0.163	t(6)= 1.11, p=0.312	t(18)= 5.22, p<0.001	t(16)= 3.35, p=0.004	t(18)= 3.05, p=0.007	t(18)= 1.57, p=0.135	t(6)= -0.31, p=0.764	
Mean	t(3)= -6.673, p=0.007	t(3)= -3.89, p=0.03	t(3)= -5.07, p=0.015	t(3)= -1.69, p=0.19	t(15)= 6.65, p<0.001	t(13)= 2,03, p=0.064	t(15)= -1.77, p=0.096	t(15)= -2.23, p=0.041	t(3)= -3.84, p=0.031	t(3)= -4.12, p=0.026

Colour explanation: White - marks significantly different beaches, according to the pollution level; Grey - marks statistically not significant different beaches.

9

Summary in Lithuanian

Įvadas

Temos aktualumas

Teršiančios medžiagos charakteristikų išsiaiškinimas yra pirmas žingsnis nustatant galimas grėsmes aplinkai. Jūrinės aplinkos tarša šiukšlėmis yra pasekmė augančių gamybos ir vartojimo procesų, kurie generuoja didelius kiekius atliekų (UNEP ir GRID-Arendal, 2016). Dirbtinės polimerinės medžiagos (dažniausiai plastikai) tampa dominuojančiu jūrą tešiančių šiukšlių tipu. Remiantis UNEP ir GRID-Arendal (2016) skelbiama informacija, šios medžiagos sudaro nuo 60 % iki 90 % paplūdimius, jūros paviršių bei dugną teršiančių šiukšlių. Siekiant įvertinti antropogeninės taršos šiukšlėmis mastą jūrinėje aplinkoje, atliekami šiukšlių kiekio paplūdimiuose tyrimai (Gago ir kt., 2014, Schulz ir kt., 2015a, Schulz ir kt., 2015b, MARLIN 2013). Vis dažniau tiriama jūrą teršiančių šiukšlių grėsmė organizmams (Avery-Gomm ir kt., 2012, Boerger ir kt., 2010, Davison P. ir Asch R.G., 2011), analizuojami šiukšlių keliai jūrinėje aplinkoje (Nauman ir kt., 2014). Tačiau informacijos apie taršos šaltinius, taršos būdą ar geografinę kilmę, patekimo į jūrinę aplinką kelius bei transportavimo sistemos viduje mechanizmus vis dar trūksta (Veiga ir kt., 2016).

Europos Parlamentui ir Tarybai priėmus Jūrų strategijos pagrindų direktyvą (JSPD) (2008/56/EC), kuri tarnauja kaip Europos Sąjungos (EU) lygmens taršos mažinimo priemonė, jūrą teršiančios šiukšlės buvo pripažintos kaip vienas iš 11 Gerą aplinkos būklę (GAB) apibūdinančių deskriptorių. Tarp 11 JSPD Direktyvos priede Nr. 1 išvardintų

GAB deskriptorių dešimtasis buvo skirtas jūrą teršiančioms šiukšlėms –„Jūrą teršiančių šiukšlių savybės ir kiekis nedaro žalos pakrančių ir jūros aplinkai“. EU Komisija taip pat nurodė aiškius kriterijus bei metodinius standartus, kuriais vadovaujantis šalys narės galės įgyvendinti JSPD (2017/848/EC). Europos Komisija (2017/848/EU) patvirtino du pirminius (D10C1 ir D10C2) ir du antrinius (D10C3 ir D10C4) kriterijus:

D10C1. Šiukšlių sudėtis, kiekis ir erdvinis pasiskirstymas pakrantėse, paviršiniame vandens storymės sluoksnyje ir ant jūros dugno yra tokio lygio, kad nedaro žalos pakrančių ir jūros aplinkai.

D10C2. Mikrošiukšlių sudėtis, kiekis ir erdvinis pasiskirstymas pakrantėse, paviršiniame vandens storymės sluoksnyje ir jūros dugno nuosėdose yra tokio lygio, kad nedaro žalos pakrančių ir jūros aplinkai.

D10C3. Šiukšlių ir mikrošiukšlių, kurias praryja jūrų gyvūnai, kiekis yra tokio lygio, kad nedaro neigiamo poveikio atitinkamų rūšių gyvūnų sveikatai.

D10C4. Kiekvienos rūšies individų, kurie dėl šiukšlių patyrė neigiamą poveikį, tokį kaip įsipainiojimą, kitų tipų sužalojimus / mirtingumą arba poveikį sveikatai, skaičius.

Šis tyrimas ženkliai papildys žinias apie D10C1 kriterijų Lietuvos Baltijos jūros ir pakrantės aplinkose. Dėl didelės gausos skirtingų mėginių ėmimo procedūrų (Hidalgo-Ruz ir kt., 2012) bei brangios analizės nustatant mikrodalelių sudėtį (Veiga ir kt., 2016) D10C2 kriterijus šiuo metu neturi standartizuotos tyrimų metodologijos. Todėl šiame darbe informacija apie D10C2 kriterijų buvo renkama daugiau dėmesio skiriant rentabilių, pakrantę teršiančių didesnių mikro- bei mezodalelių, stebėjimo metodų kūrimui.

Šiukšlių poveikis jūrų gyvūnijai ir augalijai (kriterijus 10.2.) šiame darbe nebuvo analizuotas, nes, norint apibrėžti GAB indikatorių, būtų reikalingas plačios apimties jūrinių organizmų monitoringas (Veiga ir kt., 2016).

Šiuo metu nė viena Baltijos jūros regiono šalis nevykdo šiukšlių monitoringo, apimančio visą jūrinę aplinką, įskaitant pakrantę ir akvatoriją (Veiga ir kt., 2016). Informacija apie jūrinės aplinkos taršos šiukšlėmis apimtį bei dėsningumus renkama tarptautinių mokslinių projektų įgyvendinimo metu (pvz., MARLIN, 2013). Nacionalinė jūrinę aplinką teršiančių šiukšlių tyrimus apimanti monitoringo programa yra vykdoma Vokietijoje, Meklenburgo-Pomeranijos regione. Aplinkosauginiai fondai „Keep Sweden Tidy“ ir „FEE Latvia“ remia šiukšlių monitoringo programas Švedijoje, Latvijoje ir Danijoje (Hengstmann ir kt. (2017).

Iki šiol Lietuvoje nebuvo atlikta holistinė analizė, apimanti jūrą teršiančias šiukšles bei su šiukšlėmis siejamą naštą ir įtampą socioekonominei bei gamtinei aplinkai Lietuvos Baltijos jūros pakrantėje. Jūrą teršiančias šiukšles apimantys tyrimai Lietuvos pakrantėje bei Baltijos jūros vandenyse turi suteikti reikiamos informacijos ir palengvinti JSPD reikalavimų įgyvendinimą.

Šis darbas suteikia informacijos apie Lietuvos Baltijos jūros pakrantėje ir vandenyse aptinkamų šiukšlių kiekius bei akumuliacijos dėsningumus. Buvo įvertinta esama taršos šiukšlėmis būklė, pritaikyti GAB indikatorių monitoringo metodai bei išanalizuoti galimi taršos šiukšlėmis šaltiniai. Surinkta tyrimų medžiaga bei pritaikyti tyrimų metodai paskatins jūrinę aplinką teršiančių šiukšlių ateities tyrimus. Taip pat gauti rezultatai leis nustatyti objektyvias ribines vertes, skirtas išlaikyti ar pasiekti GAB. Ši informacija prisidės prie Nacionalinių įsipareigojimų ES bei HELCOM, nustatant jūrinės aplinkos taršos šiukšlėmis Lietuvoje esamą būklę.

Tyrimo tikslai ir pagrindiniai uždaviniai

Tyrimo tikslas – įvertinti Lietuvos Baltijos jūros ir pakrantės užterštumo jūrinėmis šiukšlėmis lygį, nustatyti taršos kelius bei šaltinius ir parengti metodines rekomendacijas taršos prevencijai.

Pagrindiniai uždaviniai:

1. charakterizuoti Lietuvos pakrantės ir jūrinės aplinkos užterštumą jūrą teršiančiomis šiukšlėmis ir nustatyti taršos šaltinius;
2. atlikti skirtingų mikro- ir mezošiukšlių mėginių ėmimo metodų lyginamąją analizę ir išrinkti tinkamiausią metodą, naudotiną Lietuvos pakrantėje;
3. parengti jūros kranto savybių kaupti šiukšles vertinimo metodiką ir nustatyti Lietuvos pakrantės ruožus, kuriuose labiausiai kaupiasi jūrą teršiančios šiukšlės;
4. pateikti rekomendacijas formuojant Nacionalinę monitoringo strategiją ir nustatant jūrinės aplinkos taršos šiukšlėmis ribines vertes, kad būtų pasiekta gera jūrinės aplinkos būklė Lietuvoje.

Darbo naujumas

Šiame darbe pateikiami pirminiai rezultatai apie jūros dugną bei paplūdimius teršiančių šiukšlių kiekius, pasiskirstymą bei sudėtį Lietuvos Baltijos jūros vandenyse bei pakrantėje. Siekiant įvertinti Lietuvos jūrinės aplinkos taršos lygį buvo ištirtos skirtingos šiukšlių frakcijos (makro-, mezo, ir mikro). Pirmą kartą Lietuvoje pritaikyti ir panaudoti vizualinio tyrimo *Frame* ir *Rake* metodai. Paplūdimiuose surinktos makrošiukšlės buvo panaudotos nustatant dominuojančius taršos šiukšlėmis šaltinius bei labiausiai užterštas vietas Lietuvos Baltijos jūros pakrantėje. Erdvinės statistikos bei kranto savybių kaupti šiukšles vertinimo metodų integracija leido nustatyti labiausiai veikiamas jūrinę aplinką teršiančiomis šiukšlėmis vietas Lietuvos pakrantėje.

Darbo mokslinė ir praktinė reikšmė

Šis darbe pateikta informacija apie jūrinę aplinką teršiančias šiukšles Lietuvos Baltijos jūros akvatorijos dugne bei pakrantėje, identifikuoti atskiri objektai, šiukšlės suskirstytos pagal tipą, nustatytas jų kaupimosi dėsningumai. Darbo metu tyrimai buvo atlikti dviejose skirtingose aplinkose – atviroje jūroje ir krante, todėl panaudota skirtinga duomenų surinkimo ir apdorojimo metodika.

Atlikta Jūros akvatorijos dugną teršiančių šiukšlių erdvinės analizė, leidusi preliminariai įvertinti taršos šiukšlėmis būklę Lietuvoje. Be to, tyrimo metu gauti rezultatai sudaro pagrindą planuojant ateities tyrimus, formuojant nacionalinę monitoringo programą.

Tiriant šiukšlių kaupimosi krante ypatumus buvo pritaikytos kelios priemonės: erdvinė statistika bei jūros kranto savybių kaupti šiukšles vertinimo metodika. Tai leido nustatyti, kurie paplūdimiai yra labiau užteršti jūrą teršiančiomis šiukšlėmis, kurie kranto ruožai yra linkę kaupti šiukšles. Būtent darbo metu parengta unikali kranto savybių kaupti šiukšles vertinimo metodika sudaro prielaidas patikimai įvertinti faktorius nulemiančius šiukšlių kaupimąsi Lietuvos pakrantėje, leidžia optimizuoti nacionalinio monitoringo programą.

Galiausiai, surinkti duomenys ir gauti rezultatai yra būtini įgyvendinant pagrindinius jūrinę aplinką teršiančių šiukšlių mažinimo tikslus, iškeltus Jūrų strategijos pagrindų direktyvoje (JSPD) bei HELCOM veiksmų plane.

Ginamieji teiginiai

- Vertinant kranto taršos šiukšlėmis būklę, būtina taikyti mezo- ir mikrošiukšlių monitoringą. Dėl didelės makrošiukšlių dispersijos laiko ir erdvės atžvilgiu didesnės frakcijos šiukšlių kiekio stebėsena nesuteikia pakankamos informacijos apie smėlingų pietryčių Baltijos jūros krantų užterštumą šiukšlėmis.
- Kranto savybių kaupti jūrą teršiančias šiukšles vertinimas yra patikimas įrankis identifikuojant smėlingus paplūdimius teršiančių šiukšlių akumuliacijos vietas.
- Jūrinę aplinką teršiančių šiukšlių akumuliaciją Lietuvos krante lemia natūralios hidrodinaminės sąlygos ir kranto geometrija, išskyrus kranto atkarpas ties gyvenvietėmis bei turistų lankomomis vietomis, kur šiukšlių koncentracija didžiąja dalimi nulemta žmogaus veiklos.

Darbo rezultatų aprobavimas

Šio darbo rezultatai buvo pristatyti šešiose tarptautinėse ir dviejose nacionalinėse konferencijose.

Tarptautinės konferencijos:

5-asis IEE/OES tarptautinis Baltijos simpoziumas „Vandenynas: praeitis, dabartis ir ateitis, klimato kaita ir šiuolaikiniai tyrimų metodai“, 2012 m., Klaipėda, Lietuva;

9-asis Baltijos jūros mokslų kongresas, 2013 m., Klaipėda, Lietuva;

12-oji tarptautinė konferencija „Littoral“, 2014 m., Klaipėda, Lietuva;

10-asis Baltijos jūros mokslų kongresas, 2015 m., Ryga, Latvija;

34-oji kasmetinė „Geography of Seas and Coasts“ konferencija 2016 m., Varnemiundė, Vokietija;

11-asis Baltijos jūros mokslų kongresas, 2017 m., Rostokas, Vokietija.

Nacionalinės konferencijos:

7-oji mokslinė-praktinė konferencija „Jūros ir krantų tyrimai-2013“, 2013 m., Klaipėda, Lietuva;

8-oji mokslinė-praktinė konferencija „Jūros ir krantų tyrimai-2014“, 2014 m. Klaipėda, Lietuva.

Publikacijos

Šios disertacijos rezultatai buvo paskelbti mokslinėse publikacijose:

Balčiūnas A., Blažauskas N., 2014. Scale, origin and spatial distribution of marine litter pollution in the Lithuanian coastal zone of the Baltic Sea. Baltica, 27, Special Issue, 39-44. Vilnius. ISSN 0067-3064.

Schernewski G., **Balciunas A**., Gräwe D., Gräwe U., Klesse K., Schulz M., Wesnigk S., David Fleet , Haseler M., Nils Möllman N., Werner S., 2017. Beach macrolitter monitoring on southern Baltic beaches: results, experiences and recommendations. Journal of Coastal Conservation. ISSN 1400-0350 Printed online: https://doi.org/10.1007/s11852-016-0489-x

Haseler, M., Schernewski, G., **Balciunas, A**., Sabaliauskaite V., 2017. Monitoring methods for large micro- and meso-litter and applications at Baltic beaches. Journal of Coastal Conservation. ISSN 1400-0350. Printed online: https://doi.org/10.1007/s11852-017-0497-5

Schernewski G., Baltranaitė E., Kataržytė M., **Balčiūnas A.**, Čerkasova N., Mėžinė J., 2017. Establishing new bathing sites at the Curonian Lagoon coast: an ecological-social-economic assessment. Journal of Coastal Conservation. DOI: 10.1007/s11852-017-0587-4

Disertacijos struktūra

Disertaciją sudaro septyni skyriai: įvadas, literatūros apžvalga, medžiagos ir metodai, rezultatai, rezultatų aptarimas (mokslinė diskusija), išvados ir literatūros sąrašas, priedai ir santrauka lietuvių kalba. Disertacijos medžiaga ir rezultatai pateikti 116 puslapių, 33 paveiksluose ir 11 lentelių. Disertacijoje paminėti 105 literatūros šaltiniai. Disertacija pateikta anglų, santrauka – lietuvių kalbomis.

Padėka

Visų pirma norėčiau padėkoti savo mokslinio darbo vadovui Nerijui Blažauskui už pasitikėjimą bei patarimus doktorantūros studijų metu. Taip pat dėkoju darbo konsultantui Gerald Schernewski už suteiktas mokslinių tyrimų galimybes bei įžvalgas jūrinę aplinką teršiančių šiukšlių srityje. Dėkoju Sergej Olenin už labai vertinamus ir tinkamu laiku išsakytus paraginimus plėtoti šią darbo temą, doktorantūros studijų laikotarpiu. Taip pat norėčiau išreikšti savo padėką Olgai Anne bei a.a. Sauliui Gulbinskui, kurie paskatino mane stoti į doktorantūros studijas Klaipėdos universitete. Už išsamią darbo peržiūrą ir vertingas pastabas dėkoju Dariui Dauniui, Jūratei Lesutienei, Zitai R. Gasiūnaitei, Martynui Bučui ir Georg Umgiesser.

Esu dėkingas Kęstui Plauškai, Marijui Špėgiui ir Žuvininkystės tarnybai prie Lietuvos Respublikos Žemės ūkio ministerijos už pagalbą renkant duomenis apie jūros dugną teršiančias šiukšles. Taip pat esu dėkingas Jovitai Mėžinei už pagalbą gaunant duomenis apie vyraujančias vėjo kryptis Lietuvos pakrantėje.

Ypatinga padėka Leibnico Baltijos jūros tyrimų institutui Varnemiundėje bei BONUS BaltCoast projektui už suteiktą galimybę įgyti darbo bei komunikacijos mokslinėje bendruomenėje patirties.

Dėkoju Viačeslav Jurkin už vertingus patarimus ir konsultacijas naudojant GIS programinę įrangą. Esu dėkingas Sergej Suzdalev, Ingridai Bagdanavičiūtei, Miguel Inacio, Donaldai Karnauskaitei už diskusijas, kurios leido pažvelgti į atliekamus tyrimus iš kitos perspektyvos. Taip pat dėkoju visiems Klaipėdos universiteto bei Leibnico Baltijos jūros tyrimų instituto Varnemiundėje kolegoms už draugiškos ir darbingos atmosferos palaikymą.

Aš esu dėkingas savo žmonai, Simonai, už kantrybę ir motyvaciją judėti pirmyn sunkumų bei abejonių kupinomis dienomis. Taip pat esu dėkingas savo šeimos nariams bei draugams už kartais per dažną tačiau labai vertinamą rūpestį ir palaikymą doktorantūros studijų metu.

Santrumpų sąrašas

Santrumpa	Paaiškinimas
BITS	Tarptautinis Baltijos jūros tyrimas tralu
PTŠ	Paplūdimį teršiančios šiukšlės
GAB	Gera aplinkos būklė
HELCOM	Helsinkio komisija, Baltijos jūros aplinkos apsaugos komisija
ICES	Tarptautinė jūrų tyrimų taryba (CIEM)
FT-IR	Fourier (Furjė) transformacinis spektrometras
JRC	Jungtinių tyrimų centras prie Europos Komisijos
JTŠ	Jūrą teršiančios šiukšlės
JSPD	Jūrų strategijos pagrindų direktyva (2008/56/EC)
NATURA 2000	Specialių saugomų teritorijų Europos ekologinis tinklas
NOAA	JAV Nacionalinė vandenynų ir atmosferos administracija
OSPAR	Konvencija dėl Šiaurės Rytų Atlanto jūros aplinkos apsaugos
JDTŠ	Jūros dugną teršiančios šiukšlės
TSG-JTŠ	JSPD Techninė subgrupė dėl jūrą teršiančių šiukšlių
PA-	Poliamidas
PET-	Polietileno tereftalatas
PP-	Polipropilenas
JTAP	Jungtinių Tautų Aplinkos apsaugos programa

Tyrimų medžiaga ir metodai

Tyrimų rajonas

Tyrimai buvo atliekami dviejose jūrinės aplinkose: Baltijos jūros akvatorijos dugne ir pakrantėje (3 pav.). Lietuvos Baltijos jūros akvatorijos vidutinis gylis yra 50 m, vyraujančios dugno nuosėdos yra aleuritas, dumblas, molis, morena / rieduliai, smulkus smėlis ir žvyras-gargždas. Lietuvos Baltijos jūros pakrantė yra apie 91 km ilgio. Paplūdimio plotis svyruoja nuo keliolikos metrų ties Olando kepure iki 90 m ties Šventosios gyvenviete. Vidutinis paplūdimio plotis yra ~ 40 m, vyraujančios paviršinės nuosėdos yra smulkus ir vidutinio rupumo smėlis, žvyras, gargždas, vietomis pavieniai rieduliai.

Daroma prielaida, kad pagrindinė jūrinę aplinką teršiančių šiukšlių dalis į aplinką patenka dėl Lietuvos Baltijos jūroje vykdomos pramoninės ir rekreacinės žvejybos, laivybos. Pakrantės antropogeninė apkrova siejama su rekreaciniais paplūdimiais, netoli esančiomis urbanizuotomis teritorijomis / miestais.

Lauko tyrimai

Duomenys apie jūrinę aplinką teršiančias šiukšlės Baltijos jūros akvatorijos dugne bei pakrantėje buvo renkami 2012–2016 metais. Duomenų rinkimo metu buvo pritaikyti jau esami bei vystomi nauji šiukšlių stebėjimo aplinkoje metodai.

Makrošiukšlių stebėjimai buvo atliekami dešimtyje Lietuvos Baltijos jūros paplūdimių (5 lentelė). Iš viso buvo atlikti 86 stebėjimai, kurių metu buvo įvertintas Lietuvos pakrantės užterštumo šiukšlėmis lygis. Tyrimai buvo atliekami 2012–2016 metais, stebint paplūdimius keturis kartus per metus bei naudojant OSPAR (2010) metodologiją. Stebėjimų metu buvo identifikuojamos visos paplūdimį teršiančio šiukšlės, esančios 100 m ilgio tyrimų transektoje.

Mezo- ir didesnės frakcijos mikrošiukšlės buvo stebimos penkiuose Lietuvos Baltijos jūros paplūdimiuose (6 pav.). Stebėjimų metu buvo taikyti du tyrimo metodai pagal Haseler ir kt. (2016). Abu metodai kliaujasi paplūdimio smėlio sijojimu su 2 mm akies dydžio metaliniu sietu. Pirmasis metodas (*Frame* metodas) buvo naudojamas devyniose 1 m^2 laukeliuose, esančiose apatinėje, vidurinėje bei viršutinėje paplūdimio dalyse (5 pav. D, E, F). Antrasis metodas (*Rake* metodas) naudoja specialų smulkios frakcijos šiukšlių stebėjimams smėlyje pritaikytą griebtuvą su 2 mm akies dydžio metaliniu sietu. Naudojant *Rake* metodą paplūdimys yra suskirstomas į 0,5 m pločio ir 5 m ilgio stebėjimų transektas, išdėstytas nuo vandens linijos iki kopų vegetacijos pradžios (5 pav. A, B, C).

Makrošiukšlių pasiskirstymo paplūdimyje tyrimai 2016 m. buvo atlikti trijuose Lietuvos Baltijos jūros paplūdimiuose: Melnragė I, Melnragė II bei Giruliuose (3 pav.). Stebėjimai buvo atliekami atsižvelgiant į jau surinktus paplūdimių užterštumo šiukšlėmis duomenis makrošiukšlių stebėjimo metu. Pasitelkiant *ArcGIS online* platformą buvo sukurtas skaitmeninis paplūdimius teršiančių šiukšlių stebėjimo protokolas, apimantis dvidešimt dažniausiai randamas paplūdimius teršiančias šiukšles. Panaudojant mobilųjį telefoną buvo pažymimos visų rastų makrošiukšlių koordinatės dviejose kaimyninėse 100 m ilgio tyrimų transektose ties išėjimais į paplūdimį. Surinkti erdviniai duomenys buvo analizuojami pasitelkiant *ArcMap* programinę įrangą.

Jūros dugną teršiančios šiukšlės buvo renkamos Baltic International Trawl Surveys (BITS) stebėjimų metu. Duomenys buvo surinkti 49 ekspedicijų metu (7 pav.), bendradarbiaujant su Žuvininkystės tarnyba prie LR Žemės ūkio ministerijos. Visos šiukšlės, sugautos TV-3#520 tipo dugniniu tralu, buvo identifikuojamos pagal Tarptautinės jūrų tyrimų tarybos (ICES) koduotę (ICES, 2012).

Kranto savybių kaupti jūrą teršiančias šiukšles analizė

Kranto savybių kaupti jūrą teršiančias šiukšles analizė buvo atliekama panaudojant *ArcMap* programinę įrangą. Analizėje panaudoti antropogeninės apkrovos krantui bei gamtinių procesų parametrai (2 lentelė). Lietuvos Baltijos jūros pakrantė buvo suskirstyta į 1 km^2 gardeles, kurioms buvo įvertintos kranto savybė kaupti jūrą teršiančias šiukšles (1 formulė). Atsižvelgiant į apskaičiuotas vertes bei vadovaujantis vienodo intervalo principu, Lietuvos pakrantė buvo suskirstyta pagal penkis lygius charakterizuojančius kranto savybę kaupti jūrą teršiančias šiukšles: labai žemas, žemas, vidutinis, aukštas, labai aukštas (3 lentelė).

Makro šiukšlių taršos šaltinių nustatymas

Nagrinėjant galimus taršos šiukšlėmis šaltinius buvo pritaikytos Matricinio vertinimo (Tudor ir Wiliams, 2004) bei daiktų-indikatorių (Veiga ir kt., 2016) metodologijos. Pirmojo metodo atveju visos rastos makrošiukšlės tirtuose Lietuvos paplūdimiuose buvo įvertintos pagal tai, kokiam taršos šaltiniui (turizmas, laivyba, žvejyba, atviros jūros instaliacijos ir nuotekų sistema) jos gali priklausyti ir kokia to tikimybė (3 formulė 9 pav.). Taikant daiktais-indikatoriais paremtą metodą naudojama informacija apie aiškiai paplūdimyje atpažįstamas šiukšles bei jų galimus šaltinius (4 lentelė).

Jūros dugne bei pakrantėje rastų jūrinę aplinką teršiančių šiukšlių erdvinė bei statistinė analizė

Atliekant statistinę analizę buvo panaudotas statistinis paketas socialiniams mokslams (SPSS). Siekiant įvertinti paplūdimiuose surinktų šiukšlių šaltinio nustatymo bei kranto savybes kaupti jūrą teršiančias šiukšles reikšmių patikimumą buvo naudojama neparametrinė *Spearman* ranginė koreliacija. Ši koreliacija buvo naudojama ir tikrinant ryšį tarp jūros dugną teršiančių šiukšlių kiekio bei geomorfologinio regiono, kuriame ši šiukšlė buvo aptikta.

Siekiant nustatyti paplūdimių panašumą pagal užterštumą šiukšlėmis, buvo atliktos dvi skirtingos klasterinės analizės panaudojant Ward metodą. Pirmosios klasterinės analizės metu kaip panašumo tarp paplūdimių parametras buvo naudojamas bendras paplūdimio užterštumas (vidutinis šiukšlių kiekis šimtui metrų paplūdimio). Antrosios klasterinės analizės metu panašumo tarp paplūdimių parametru buvo naudojamas devynių dažniausiai randamų paplūdimius teršiančių šiukšlių vidutinis kiekis šimtui metrų paplūdimio.

Erdvinė statistinė analizė buvo atliekama naudojant *ArcMap* programinę įrangą. Analizėje naudoti erdvinės statistikos įrankiai: klasterių ir riktų (*Anselino vietinė Morano I*) bei karštųjų zonų (hot spot) analizės. Analizė buvo atlikta nagrinėjant Lietuvos Baltijos jūros dugne bei paplūdimiuose rastas šiukšles (10 pav.). Analizei atlikti buvo sukurtas erdvinis tinklelis, kurio gardelių dydis buvo paremtas *in situ* matavimų metu nustatyta informacija: vidutinis dugno tralavimo ilgis (3,5 km) bei vidutinė GPS paklaida, užfiksuota stebėjimų metu (5 metrai).

Rezultatai

Rezultatai pristatyti keturiuose skyriuose: 1) Šiukšlių charakteristikos jūrinėje ir pakrantės aplinkose, 2) Erdvinis jūrinę aplinką teršiančių šiukšlių pasiskirstymas, 3) Kranto savybės kaupti jūrą teršiančias šiukšles, 4) Paplūdimiuose aptinkamų jūrinę aplinką teršiančių šiukšlių šaltiniai.

Pirmame skyriuje pateikti rezultatai, apimantys paplūdimius teršiančių makro-, mezo- ir stambesnės frakcijos mikrošiukšlių kiekių bei tipų pasiskirstymą tirtuose paplūdimiuose. Taip pat pristatyti Baltijos jūros dugno tralavimo metu sugautų šiukšlių tipai, kiekiai ir tankis.

Lietuvos Baltijos jūros paplūdimiuose vidutiniškai buvo aptikta 164,7 vnt/100m šiukšlių. Paplūdimiuose surinktų šiukšlių kiekis svyravo nuo 31 vnt/100m iki 422 vnt/100m. Palyginus vidutinį šiukšlių kiekį stebėtuose paplūdimiuose (14 pav.) pastebėta, kad Klaipėdos paplūdimys (Melnragė) buvo labiausiai užterštas šiukšlėmis (vidutiniškai 299,2 vnt/100m). Tuo tarpu Nidos paplūdimyje buvo aptikta mažiausiai jūrinę aplinką teršiančių šiukšlių: vidutinis šiukšlių kiekis čia tesiekė 60,5 vnt/100m. Palyginus sezoninę šiukšlių kiekio kaitą tirtuose paplūdimiuose buvo nustatyta silpna teigiama koreliacija ($\rho=0{,}393$, $p<0{,}01$) tarp vidutinio šiukšlių kiekio ir metų laiko. Lietuvos Baltijos jūros paplūdimiai labiausiai užteršti šiukšlėmis yra rudenį (13 pav.). Paplūdimiuose dominuoja dirbtinių polimerų medžiagos (83%) (14 pav.). Plastiko / polistireno fragmentai (diametras 2,5 cm> < 50 cm) (41,6 %) ir cigarečių nuorūkos (13 %) buvo dažniausiai aptinkamos (6 lentelė).

Atlikus 49 Baltijos jūros dugno tralavimus nustatyta, kad net 83,7 % atvejų buvo aptikta nors viena jūrinę aplinką teršianti šiukšlė. Be to, nustatyta, kad tirtose vietose šiukšlių tankis vidutiniškai yra 111,6 vnt/km^2. Palyginus rastų šiukšlių sudėtį nustatyta, kad dominavo dirbtinių polimerų medžiagos (71%) (15 pav.). Jūros aplinką teršiančių šiukšlių kiekiai buvo vertinami ir atsižvelgiant į dugno paviršinių nuogulų tipą. Nustatyti toks šiukšlių tankis: žvyru, gargždu ir įvairios frakcijos smėliu padengtame dugne šiukšlių kiekis – 163,6 vnt/km^2 (N=3), aleuritu – 129,2 vnt/km^2, (N=13), dumblu – 117,7 vnt/km^2 (N= 17) ir smulkiu smėliu – 115,0 vnt/km^2 (N=15). Atlikus šiukšlių kiekio ir paviršinių nuogulų, ant kurių rasta šiukšlė, priklausomybės analizę, nebuvo nustatyta, kad yra aiški ir statistiškai reikšminga priklausomybė. Palyginus jūrą teršiančių šiukšlių pasiskirstymą skirtinguose Lietuvos jūrinės akvatorijos geomorfologiniuose regionuose (7 lentelė) nustatyta, kad Nemuno proslėnyje šiukšlių koncentracija buvo didžiausia (171,9 vnt/km^2, N= 6). Didžiausias šiukšlių kiekis vieno tralavimo metu buvo užfiksuotas Gotlando bei Gdansko baseinų šlaituose (467,8 vnt/km^2). Didžiąją dalį visų šiukšlių sudarė dirbtinių polimerų (plastikiniai) lakštai (20,8 %), maišeliai (18,1 %) bei dirbtinių polimerų fragmentai (10,9 %).

Atlikus mažesnės frakcijos mezošiukšlių (5mm–25mm) ir stambesnių mikrošiukšlių (2mm–5mm) stebėjimus penkiuose Lietuvos Baltijos jūros paplūdimiuose nustatyta vidutinė reikšmė yra 1,8 vnt/m^2. Iš visų Lietuvos plūdimuose esančių mažesnės frakcijos dalelių parafinas sudarė didžiąją dalį (41 %). Dirbtinių polimerų medžiagos vidutiniškai sudarė 38 % visų aptiktų šiukšlių dalelių. Palyginus du naudotus šiukšlių stebėjimo metodus nustatyta, kad nepaisant vidutiniškai mažesnio aptinkamų šiukšlių dalelių kiekio viename kvadratiniame metre *Rake* metodas (1,40±0,37) pasižymėjo reikšmingai mažesne randamų dalelių dispersija, palyginus su *Frame* metodu (2,07±1,38).

Antrame skyriuje pateikiami rezultatai, apimantys erdvinį makrošiukšlių pasiskirstymą paplūdimiuose ir jūros dugne, ir paplūdimių panašumo pagal užterštumo lygį analizės rezultatai.

Atliktas paplūdimių erdvinis grupavimas naudojant *Hot Spot* ir *Morans I* metodus parodė, kad šiukšlės paplūdimiuose labiausiai kaupiasi ties esama infrastruktūra (persirengimo kabinos, šiukšliadėžes, lauko kavinės ir pan.) (17 pav.). Taip pat pastebėta, kad didžioji dalis šiukšlių kaupiasi apie 50 m atstumu nuo įėjimo į paplūdimį. Statistiškai reikšmingas šiukšlių kaupimasis ties paplūdimio infrastruktūra patvirtino, kad didžioji dalis paplūdimiuose surenkamų šiukšlių yra siejamos su iš kranto patenkančia tarša (dažniausiai atnešamos turistų).

Įvertinus jūros dugne surinktų šiukšlių paplitimo ypatumus pastebėta, kad šiukšlės tankiausiai paplitusios yra centrinėje akvatorijos dalyje bei Nemuno proslėnyje (18 pav.). Palyginus du skirtingus erdvinio grupavimo metodus (Hot Spot ir Morans I) pastebėta, kad nustatytus, galimus jūros dugne besikaupiančių šiukšlių židinius ties Kaipėdos–Ventspilio bei Kuršių–Sambijos plynaukštėmis nulėmė pavieniai dideli šiukšlių kiekiai, nustatyti atskirų stebėjimų metu.

Atlikus paplūdimių hierarchinę klasterizaciją pagal bendrą užterštumo šiukšlėmis paplūdimyje lygį bei devynias dažniausiai aptinkamas ir atpažįstamas šiukšles pastebėti tie patys grupavimosi dėsningumai (19 pav.). Sugrupavus paplūdimius pagal bendrą užterštumo šiukšlėmis lygį nustatytos trys grupės paplūdimių: mažiausiai užteršti (Juodkrantė, Šventoji S, Šventoji N ir Nida), vidutinio užterštumo (NordBalt koridorius, Smiltynė, Nemirseta, Palanga) bei labiausiai užteršti (Klaipėda ir Karklė). Sugrupavus paplūdimius pagal dažniausiai aptinkamas šiukšles NordBalt koridoriuje esantis paplūdimys išsiskyrė kaip unikali vieta, kurioje šiukšlės yra daugiausia susijusios su jūrine veikla. Taip pat nustatytos dvi grupės paplūdimių, kurias sudarė: 1) piečiausiai ir šiauriausiai esantys paplūdimiai, 2) centrinėje Lietuvos Baltijos jūros pakrantėje esantys paplūdimiai. Atlikus *t-test* analizę palyginant vidutinius šiukšlių kiekius tarp nagrinėjamų paplūdimių nustatyta, kad Klaipėdos ir Karklės paplūdimiai yra unikalūs pagal savo aukštą bendrą užterštumo lygį (A1 lentelė prieduose).

Trečiame skyriuje pateikiami kranto taršumo šiukšlėmis bei šiukšlių kaupimosi krante ypatumus bei riziką apimančių faktorių analizės rezultatai.

Įvertinus kranto savybes kaupti šiukšles reikšmes Lietuvos Baltijos jūros pakrantėje nustatyta, kad daugiau nei du trečdaliai pakrantės ruožų yra laikytini kaip mažai (34,5 %) ir vidutiniškai (29,9 %) kaupiantys jūrą teršiančias šiukšles. Tik 5,7 % Lietuvos pakrantės yra laikytinos kaip labai kaupiančios šiukšles atkarpos; jos yra išsidėsčiusios žemyniniame Lietuvos Baltijos jūros krante. Labiausiai šiukšlės kaupiasi ties didžiausiomis gyvenvietėmis: Klaipėda bei Palanga (20 pav.). Tuo tarpu piečiausios ir šiauriausios Lietuvos pakrantės atkarpos turi mažiausią potencialą kaupti šiukšles.

Įvertinus faktorius, lemiančius kranto savybes kaupti šiukšles, nustatyta, kad gamtos veiksniai daro didžiausią įtaką šiukšlių kaupimuisi krante. Nustatyta, kad vidutiniškai 66 % verčių nulemti gamtinės kilmės faktorių (vyraujanti vėjo kryptis, paviršinio vandens sluoksnio srovės ir bangos kryptys, gėlo vandens (pliumo) zona / atstumas iki upės (šiuo atveju Klaipėdos sąsiaurio žiočių). Vertinat Lietuvos pakrantės mastu, pastebimas antropogeninės apkrovos aplinkai parametrų reikšmingumo padidėjimas artėjant prie Klaipėdos miesto bei Klaipėdos sąsiaurio (21 pav.). Lyginant Kuršių Nerijos pakrantę su žemyniniu krantu matoma, kad Kuršių Nerijos pakrantėje šiukšlių kaupimąsi nulemiantys parametrai kinta tolygiai. Tuo tarpu tolstant į šiaurę nuo Klaipėdos sąsiaurio matomas staigus ir dažnas šiukšlių kaupimąsi lemiančių faktorių reikšmingumo pasikeitimas (21 pav.).

Nustatyta labai stipri teigiama Spearmano ranginė koreliacija ($\rho=0,848$, $p<0,01$) tarp kranto savybių kaupti šiukšles verčių bei vidutinių šiukšlių kiekių nagrinėjamuose paplūdimiuose rodo, kad kranto savybių kaupti šiukšles vertinimas leidžia nustatyti pakrantės atkarpas, kur paplūdimius teršiančių šiukšlių kiekis yra didžiausias. Nustatyti labai stiprūs ir statistiškai reikšmingi ryšiai tarp įvairių šiukšlių: cigarečių nuorūkų ($\rho=0,736$ $p<0,05$), plastikinių maišelių ($\rho=0,835$ $p<0,01$), plastikinių butelių ($\rho=0,720$ $p<0,05$) ir suminės antropogeninės apkrovos aplinkai parametrų vertės, todėl galima teigti, kad tarša minėtais objektais yra antropogeninės kilmės.

Ketvirtame skyriuje yra pateikiami galimų jūrinę aplinką teršiančių šiukšlių šaltinių nustatymo analizės rezultatai. Buvo taikyti du: Matricinio vertinimo bei daiktų-indikatorių taršos šiukšlėmis šaltinių nustatymo metodai.

Įvertinus galimus taršos šaltinius, naudojant Matricinio vertinimo metodą, buvo nustatyta, kad su turizmu siejamos šiukšlės sudaro apie 56 % paplūdimių taršos. Tuo tarpu įvertinus galimus taršos šaltinius naudojant daiktų-indikatorių metodą, pastebėta, kad su turizmu susijusi veikla lemia net 74,9 % taršos. Turizmo sukeliama tarša ryškiausia Palangoje, kur su turizmu siejamos šiukšlės sudarė 61,1 % vertinat pagal Matricinio vertinimo metodą bei 82,0 % vertinat pagal daiktų-indikatorių daiktų metodą. Žemyninės kilmės taršos šaltiniai (turizmas ir nuotekų valymo sistemos) turi didesnę įtaką žemyniniame Lietuvos Baltijos jūros krante, tuo tarpu šiukšlės, susijusios su jūrinės kilmės šaltiniais (laivyba, žvejyba bei infrastruktūra atviroje jūroje), dažniau aptinkamos Kuršių nerijos krante.

Įvertinus ryšį tarp nustatytų paplūdimio taršos šiukšlėmis šaltinių reikšmingumo ir suminės antropogeninės apkrovos aplinkai parametrų verčių, nustatyta, kad su turizmu siejama tarša yra statistiškai reikšminga (stiprus teigiamas ryšys). Įvertinus ryšį tarp nustatytų paplūdimio taršos šiukšlėmis šaltinių (žvejyba, laivyba, infrastruktūra atviroje jūroje ar net nuotekų valymo sistemos) reikšmingumo verčių ir suminės gamtinių kilmės faktorių vertės patikimai stiprios priklausomybės nustatyti nepavyko (11 lentelė).

Diskusija

Diskusija susideda iš keturių skyrių: 1) Jūrinę aplinką teršiančių šiukšlių pasiskirstymas, charakteristikos ir galimi šaltiniai, 2) Kranto charakteristikų svarba paplūdimius teršiančių šiukšlių stebėsenai, 3) Socioekonominė jūrinę aplinką teršiančių šiukšlių reikšmė Lietuvoje, 4) Rekomendacijos paplūdimius teršiančių šiukšlių stebėsenai Lietuvoje.

Pirmame skyriuje yra aptariama sezoninė ir erdvinė jūrinę aplinką teršiančių šiukšlių kaita, pateikiamos paplūdimiuose surinktų šiukšlių charakteristikos ir galimi taršos šaltiniai. Yra pabrėžiama, kad paplūdimius teršiančių šiukšlių kiekis paplūdimiuose yra tiesiogiai susijęs su rekreacijos intensyvumu pakrantėje. Pažymima, kad šiltuoju metu šiukšlių paplūdimiuose mažinimo priemonės, ypatingai tokios kaip paplūdimių valymas, yra vykdomos. O tai, atsižvelgiant į Velander ir Mocogni (1998), Moore ir kt. (2001) bei Somerville ir kt. (2003), turi reikšmingos įtakos nustatant realius taršos kiekius. Kitą vertus, tai, kad didžiausi šiukšlių kiekiai randami rudens sezonu rodo, jog šiukšlių paplūdimyje kiekį lemia metų laikų pasikeitimas iš ramaus ir šilto periodo į šaltesnį bei audringesnį. Atkreipiamas dėmesys, kad labai svarbu išlaikyti tinkamą paplūdimių valymo dažnumą po šiltojo metų laiko, pasibaigus intensyviausiai rekreacijai paplūdimyje.

Nustatytas silpnas ryšys tarp paplūdimius teršiančių šiukšlių ir metų laiko gali būti dėl didelės aptinkamų šiukšlių dispersijos. Didelė dispersija yra fiksuojama ne tik šiame darbe, tačiau ir tyrimuose, apimančiuose didesnius jūros regionus. Vadovaujantis Jungtinių Tautų Aplinkosaugos Programa bei Viduržemio jūros veiksmų planu (UNEP/MAP, 2015), galima teigti, kad šiukšlių paplūdimyje kiekis, tenkantis 100 m paplūdimio, gali kisti nuo 25 vnt. Italijoje iki 1993 vnt. Kroatijoje.

Atkreipiamas dėmesys, jog dėl fragmentuoto paplūdimių valymo (šiukšlės renkamos tik rekreaciniuose paplūdimiuose) bei nustatytos didelės rastų šiukšlių kiekio dispersijos, makrošiukšlių stebėjimai galimai neatspindi, koks yra tikras paplūdimių užterštumas jūrą teršiančiomis šiukšlėmis. Makrošiukšlės yra lengvai pastebimos ir valant paplūdimius pakeliamos, tačiau smulkesnės frakcijos dalelės lieka paplūdimyje. Paskutiniu metu vis daugiau dėmesio skiriant smulkesnei šiukšlių frakcijai (< 5mm), iškyla tinkamo jų tyrimo metodo parinkimo klausimas. Pagal Hidalgo-Ruz ir kt. (2012), vizualine charakterizacija paremti metodai yra labiausiai paplitę ne tik dėl savo paprastumo, tačiau ir dėl savo rentabilumo. Šiame darbe pritaikyti du smulkesnės frakcijos šiukšlių stebėjimo metodai gali būti naudojami kaip papildomi, šalia tradicinio makrošiukšlių stebėjimo paplūdimyje.

Atlikti jūros dugno užterštumo šiukšlėmis tyrimai rodo, kad šiuo atžvilgiu Lietuvai priklausanti Baltijos jūros dugno dalis nėra išskirtinė, o jūros dugne randamų šiukšlių kiekio dispersija yra gana didelė (Galgani ir kt., 2000). Šio tyrimo metu surinkti duomenys atskleidė, kad daugiausiai šiukšlių yra aptinkama centrinėje Lietuvos Baltijos akvatorijos dalyje, šalia intensyviausio laivybos eismo koridorių. Tai patvirtina Galgani ir kt. (2000) padarytą prielaidą, kad antropogeninės veiklos intensyvumas turi įtakos jūros dugno besikaupiančių šiukšlių kiekiui. Įvertinus atstumą (> 30 km) iki didžiausią šiukšlių koncentraciją turinčios teritorijos bei atsižvelgiant į Ferrarin ir Umgiesser (2013) nustatytą priedugnio srovės vyraujančia kryptį (į šiaurę), galima teigti, kad šiukšlės, patenkančios į jūrą per Klaipėdos sąsiaurį, greičiausiai yra išmetamos į paplūdimį, o ne akumuliuojasi centrinėje Lietuvos Baltijos akvatorijos dalyje.

Vizualinis paplūdimio užterštumo šiukšlėmis įvertinimas yra tinkamas pirminiam taršos šiukšlėmis vertinimui. Tačiau vertinant galimus taršos šiukšlėmis šaltinius yra būtina aiškiai identifikuoti randamus daiktus. Kartais tai gali būti sudėtinga padaryti dėl šiukšlių fragmentacijos, todėl yra aptinkamas didelis kiekis dirbtinių polimerų medžiagų fragmentų kiekis paplūdimiuose. Kaip dalelių fragmentacija, taip pasirinktas metodas turi įtakos galutiniam taršos šiukšlėmis šaltinio reikšmingumo nustatymui. Tai buvo iliustruota panaudojus du skirtingus taršos šiukšlėmis šaltinio nustatymo metodus, kurie parodė tą pačią bendrą tendenciją, tačiau skirtingą taršos šaltinių reikšmingumą paplūdimiuose.

Antrame skyriuje yra aptariama kranto ir jūrinės aplinkos charakteristikų svarba planuojant, atliekant ir analizuojant paplūdimių užterštumo šiukšlėmis tyrimus. Buvo pabandyta sukurti kranto savybes kaupti šiukšles vertinimo metodiką, integruojančią kranto savybes kaupti šiukšles ir taršos riziką. Nepaisant esamos praktikos (Kubota, M., 1994, Kubota, M. ir kt., 2005, Maximenko ir kt., 2011), kuri remiasi matematiniais modeliais paremtomis simuliacijomis ir hidrodinaminiu modeliavimu, šiame darbe pritaikyta metodika didesnį dėmesį sutelkia į galimybę įvertinti galimus taršos kelius ir šaltinius, susijusius su sausuma, esančia šalia jūrinės aplinkos. Gauti rezultatai įrodė, kad kranto charakteristikos ir jų suminės vertės turi įtakos vertinant kranto savybes kaupti šiukšles ir taršos riziką. Taip pat pastebėta, kad suformuota metodika gali tinkamai reprezentuoti paplūdimius teršiančių šiukšlių kaupimąsi, nepaisant didelės šiukšlių kiekio paplūdimyje lokalios ir regioninės dispersijos.

Jūrinę aplinką teršiančios šiukšlės yra antropogeninės veiklos rezultatas, tačiau joms patekus į jūrinę aplinką, jos tampa priklausomos nuo gamtinių veiksnių ir dėsnių. Dėl šios priežasties gamtinės kilmės faktoriai ir nulemia jūrinę aplinką teršiančių šiukšlių transportavimą ir pasiskirstymą. Šio darbo rezultatai atspindi faktą, kad skirtingą Lietuvos Baltijos jūros paplūdimių užterštumo šiukšlėmis lygį lemia gamtinės kilmės faktoriai. Svarbu paminėti, kad pagrindinis paplūdimyje nustatytų šiukšlių šaltinis yra turistai ir poilsiautojai paplūdimyje, o kiti taršos šaltiniai yra ne tokie reikšmingi. Taip pat svarbu paminėti, kad antropogeninė apkrova aplinkai padidėja ties didesnėmis gyvenvietėmis bei rekreacinėmis teritorijomis, todėl būtent tose vietose turėtų būti taikomos pagrindinės taršos sukelto poveikio mažinimo priemonės.

Trečiame skyriuje yra aptariama socioekonominė jūrą teršiančių šiukšlių įtaka Lietuvoje. Pasaulyje yra pavyzdžių, rodančių, kad jūrinę aplinką teršiančios šiukšlės gali sukelti ilgalaikius bei milijoninius nuostolius dėl sumažėjusios rekreacinės, estetinės ir edukacinės jūrinės aplinkos vertės (Mouat et al., 2010). Šio darbo metu nustatytos šiukšlių koncentracijos paplūdimyje rodo, kad finansinė grėsmė siejama su paplūdimius teršiančiomis šiukšlėmis yra minimali. Tačiau svarbu paminėti, kad šiukšlės paplūdimyje sukelia papildomas išlaidas ir Lietuvoje. Remiantis diskusijų su atliekų tvarkytojais metu surinkta informacija buvo apskaičiuota, kad apie 49 km pakrantės priežiūra (šiukšlių surinkimas ir utilizavimas) Lietuvai kasmet kainuoja apie 600 000 EUR. Taip pat išlaidų personalui reikalauja ir šiukšlių monitoringas, tačiau lyginat su išlaidomis, reikalingomis utilizuoti paplūdimiuose surinktas šiukšles, šie kaštai yra mažareikšmiai.

Ketvirtame skyriuje yra pateikiamos rekomendacijos kaip objektyviai ir reprezentatyviai atlikti jūrinės aplinkos taršos šiukšlėmis stebėseną. Paplūdimius teršiančių makrošiukšlių monitoringas turi gerai apibrėžtą bei pastovią metodologiją, kurią jau kelis dešimtmečius sėkmingai naudoja Oslo ir Paryžiaus konvenciją pasirašiusios šalys. Tačiau duomenų kiekis apie paplūdimius teršiančias šiukšles kituose ES Jūrų regionuose, įskaitant ir Baltijos jūrą, nėra toks didelis, kaip Šiaurės Vakarų Atlanto ir Šiaurės jūros regione. Dėl šios priežasties ilgalaikiai ir plačios apimties tyrimai yra labai svarbūs nustatant ribines vertes apibrėžiančias Gerą aplinkos būklę (GAB).

Šiuo metu paplūdimiuose besikaupiančių šiukšlių monitoringas yra pradedamas vis didesnėje dalyje Europos valstybių. Vertinant surinktą informaciją bei gautus rezultatus yra aišku, kad šiukšlių monitoringas Lietuvoje turėtų būti vykdomas vadovaujantis OSPAR Komisijos arba TSG-JTŠ stebėjimų metodikomis, kurios yra paremtos šiukšlių stebėjimais 100 m paplūdimio atkarpose.

Nacionalinio lygio jūrą teršiančių šiukšlių monitoringo strategijos vystymas yra būtinas, laikantis EU Komisijos pateiktų kriterijų bei metodinių standartų (2017/848/EC). Atsižvelgiant į šio darbo rezultatus ir įgytą patirtį jūrą teršiančių šiukšlių tyrimų srityje, siūlomos šios rekomendacijos:

- Paplūdimyje susikaupusios šiukšlės turi būti stebimos 100 metrų ilgio transektose. Visos rastos šiukšlės turi būti surenkamos.
- Monitoringo vietos turi būti prieinamos stebėtojams visus metus. Monitoringo vietų koordinatės turi būti fiksuojamos, siekiant pakartotinius stebėjimus atlikti tose pačiose paplūdimio atkarpose. Šiukšlių monitoringas turi būti atliekamas šiose Lietuvos Baltijos jūros pakrantės atkarpose: Nida–Juodkrantė, Kuršių nerija (į pietus nuo NordBalt jungties koridoriaus), Klaipėda–Karklė, Nemirseta–Palanga.
- Nustatytose atkarpose paplūdimyje besikaupiančių šiukšlių monitoringas atliekamas 4 kartus per metus, visais metų sezonais (pavasarį, vasarą, rudenį ir žiemą). Tai leistų užtikrinti rezultatų sezoniškumą bei sudarytų galimybes lyginti tyrimo rezultatus tarptautiniu ir tarpregioniniu lygmeniu.
- Paplūdimyje randamų šiukšlių surašymas turi būti atliekamas pagal OSPAR Komisijos (2010) pateiktas paplūdimiuose besikaupiančių šiukšlių monitoringo gaires. Gairių laikymasis atliekant monitoringą užtikrins, kad paplūdimiuose surenkamos šiukšlės bus klasifikuojamos pagal standartizuotą sudedamosios medžiagos tipą: dirbtinių polimerų medžiagos, guma, tekstilė, popierius / kartonas, apdorota mediena, metalas, stiklas / keramika, cheminės medžiagos, neidentifikuojama ir maistinės atliekos.
- Atliekant šiukšlių monitoringą, šalia makrošiukšlių analizės rekomenduojama tirti ir mezo- bei didesnes mikrošiukšles naudojant *Rake* metodą. Kompleksinis makro- ir smulkesnių šiukšlių tyrimas užtikrins tarptautinių rekomendacijų (JRC, 2013) jūrą teršiančių šiukšlių monitoringui įgyvendinimą.

IŠVADOS

1. Jūros aplinką teršiančios šiukšlės yra plačiai paplitusios tiek krante (rasta visais paplūdimiuose vykdomų tyrimų atvejais) tiek ant jūros dugno (tik 16 % atvejų šiukšlių jūros dugne nebuvo aptikta). Dirbtiniai polimerai yra dominuojanti jūrinę aplinką teršiančių šiukšlių medžiaga, kuri sudarė 71 % jūros dugne ir 83% krante surinktų dalelių.
2. Jūra teršiančios šiukšlės labiausiai kaupiasi jūros dugno įdubose (zonose, kur jūros dugne greitai keičiasi hidrodinaminės sąlygos) – Nemuno proslėnyje ir Gotlando bei Gdansko baseinų šlaituose, taip pat netoli intensyvios laivybos koridorių.
3. Lietuvos krantų tarša jūrinę aplinką teršiančiomis šiukšlėmis labai kaiti tiek erdvine, tiek laiko prasme. Labiausiai užteršti yra paplūdimiai, esantys netoli urbanizuotų teritorijų. Labiausiai užteršti yra žemyninio Baltijos jūros kranto paplūdimiai: ties Klaipėda ir ties Karkle. Turizmas / visuomenė – lemia net iki 75 % šiukšlių Klaipėdos miesto paplūdimiuose. Kita labiausiai teršianti ūkinė veikla – žvejyba, su kuria susijusios šiukšlės sudaro net iki 45 % Kuršių nerijos paplūdimiuose surenkamų šiukšlių.
4. Paplūdimių taršos stebėsena, pagrįsta didesnių mikro- ir mezošiukšlių tyrimu, yra tikslesnė, siekiant nustatyti smėlingų paplūdimių užterštumo jūrinę aplinką teršiančiomis šiukšlėmis lygį. Papildoma statistinė skirtingų mikro- ir mezošiukšlių mėginių ėmimo metodų lyginamoji analizė parodė, kad *Rake* metodas tiksliau reprezentuoja Lietuvos paplūdimių užterštumą šiukšlėmis, lyginat su *Frame* metodu.
5. Lietuvos smėlingų krantų savybės kaupti jūrinę aplinką teršiančias šiukšles ir jų kiekis tiesiogiai priklauso nuo gamtinių parametrų ir žmogaus veiklos. Nustatyta, kad ryšys tarp kranto savybės kaupti šiukšles ir paplūdimyje surinktų jūrinę aplinką teršiančių šiukšlių kiekio yra statistiškai reikšmingas bei labai stiprus ($\rho=0,848$, $p<0,01$). Labiausiai jūrinę aplinką teršiančios šiukšlės kaupiasi paplūdimiuose, esančiuose netoli pagrindinių gyvenviečių (Klaipėdos ir Palangos) – Smiltynės, Melnragės, Karklės ir Palangos paplūdimiuose. Nepaisant to, didžiojoje Lietuvos kranto dalyje (~ 84 %) šiukšlių kaupimasis gali būti vertinamas kaip mažai intensyvus arba vidutinis.
6. Nacionalinis Lietuvos pakrantės taršos jūrinę aplinką teršiančiomis šiukšlėmis monitoringas turi būt paremtas kranto savybių kaupti šiukšles tyrimo rezultatais. Makrošiukšlių stebėsena turi būti papildyta didesnių mikro- ir mezošiukšlių tyrimu (naudojant *Rake* metodą). Rekomenduotina, kad šiukšlių stebėsena būtų vykdoma 4 kartus per metus (kiekvieną sezoną) keturiuose kranto ruožuose: Nida–Juodkratė, Kuršių nerija (į pietus nuo NordBalt jungties koridoriaus), Klaipėda–Karklė ir Nemirseta–Palanga.

Klaipėdos universiteto leidykla

Arūnas Balčiūnas
MARINE LITTER POLLUTION AT THE LITHUANIAN OPEN SEA AND COASTAL AREAS
Doctoral dissertation

LIETUVOS BALTIJOS JŪROS IR PAKRANTĖS TARŠA ŠIUKŠLĖMIS
Daktaro disertacija

Klaipėda, 2018

SL 1335. 2018 01 24. Apimtis 9,45 sąl. sp. l. Tiražas 35 egz.
Išleido ir spausdino Klaipėdos universiteto leidykla, Herkaus Manto g. 84, 92294 Klaipėda
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