KLAIPĖDA UNIVERSITY

Greta SRĖBALIENĖ

QUANTITATIVE ASSESSMENT OF BIOINVASION IMPACTS ON MARINE ECOSYSTEMS

DOCTORAL DISSERTATION

Natural sciences,
ecology and environmental sciences (N 012)

Klaipėda, 2019

Doctoral dissertation was prepared in the period 2010–2019 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-1019, signed on 8 June 2011, and by the order of Minister of Education, Science and Sport (Republic of Lithuania) No. V-160, signed on 22 February 2019.

Academic advisor

prof. dr. Sergej OLENIN (Klaipėda University, Natural Sciences, Ecology and Environmental Sciences – N 012).

The doctoral dissertation is defended at the Board of Klaipėda University in Ecology and Environmental Sciences:

Chairman

doc. dr. Zita Rasuolė GASIŪNAITĖ (Klaipėda University, Natural Sciences, Ecology and Environmental Sciences – N 012).

Members:

prof. habil. dr. Mariusz Remigiusz SAPOTA (University of Gdansk, Poland, Natural Sciences, Ecology and Environmental Sciences – N 012);
dr. Denis COPILAŞ-CIOCIANU (Nature Research Centre, Natural Sciences, Ecology and Environmental Sciences – N 012);
dr. Renata PILKAITYTĖ (Klaipėda University, Natural Sciences, Ecology and Environmental Sciences – N 012);
dr. Martynas BUČAS (Klaipėda University, Natural Sciences, Ecology and Environmental Sciences – N 012).

The dissertation will be defended in a public meeting of the Board in Ecology and Environmental Sciences, Klaipėda University, Marine Research Institute Conference hall (201) at 1 p. m. on the 18 of October, 2019.
Address: Universiteto alley 17, LT-92294, Klaipėda, Lithuania.

The doctoral dissertation was sent out on the 18 of September, 2019.
The doctoral dissertation is available for review at the Library of Klaipėda University.

KLAIPĖDOS UNIVERSITETAS

Greta SRĖBALIENĖ

BIOLOGINIŲ INVAZIJŲ POVEIKIO JŪRŲ EKOSISTEMOMS KIEKYBINIS VERTINIMAS

DAKTARO DISERTACIJA

Gamtos mokslai,
ekologija ir aplinkotyra (N 012)

Klaipėda, 2019

Disertacija rengta 2010–2019 metais Klaipėdos universitete pagal Lietuvos Respublikos švietimo ir mokslo ministro 2011 m. birželio 8 d. įsakymu Nr. V-1019 ir Lietuvos Respublikos švietimo, mokslo ir sporto ministro 2019 m. vasario 22 d. įsakymu Nr. V-160 Klaipėdos universitetui suteiktą Ekologijos ir aplinkotyros mokslo krypties doktorantūros teisę.

Vadovas

prof. habil. dr. Sergej OLENIN (Klaipėdos universitetas, gamtos mokslai, ekologija ir aplinkotyra – N 012).

Daktaro disertacija ginama Klaipėdos universiteto Ekologijos ir aplinkotyros mokslo krypties taryboje:

Pirmininkas

doc. dr. Zita Rasuolė GASIŪNAITĖ (Klaipėdos universitetas, gamtos mokslai, ekologija ir aplinkotyra – N 012).

Nariai:

prof. habil. dr. Mariusz Remigiusz SAPOTA (Gdansko universitetas, Lenkija, gamtos mokslai, ekologija ir aplinkotyra – N 012);
dr. Denis COPILAŞ-CIOCIANU (Gamtos tyrimų centras, gamtos mokslai, ekologija ir aplinkotyra – N 012);
dr. Renata PILKAITYTĖ (Klaipėdos universitetas, gamtos mokslai, ekologija ir aplinkotyra – N 012);
dr. Martynas BUČAS (Klaipėdos universitetas, gamtos mokslai, ekologija ir aplinkotyra – N 012).

Daktaro disertacija bus ginama viešame Ekologijos ir aplinkotyros mokslo krypties tarybos posėdyje 2019 m. spalio 18 d. 13 val. Klaipėdos universiteto Jūros tyrimų instituto Konferencijų salėje (201 a.).
Adresas: Universiteto alėja 17, LT-92294, Klaipėda, Lietuva.

Daktaro disertacija išsiųsta 2019 m. rugsėjo 18 d.
Disertaciją galima peržiūrėti Klaipėdos universiteto bibliotekoje.

Abstract

The phenomenon of biological invasions, or the human-mediated movement of non-indigenous species (NIS) to areas where they did not previously occur, increasingly attracts attention not only of scientists, but also environmental policy makers and industry. The study of biological invasions became a complex interdisciplinary scientific research area, which involves both fundamental and applied aspects. The present work is devoted to the analysis of the biological invasions impacts and risk assessment methods, which are needed both for theoretical studies and practical management of biological invasions. At first, the requirements of international and European legislation were analyzed with the aim to develop the criteria and a scoring system for the evaluation of the appropriateness of the bioinvasion impact and risk assessment methods. Then the scoring system based on the key risk assessment (RA) principles, RA components and categories of bioinvasion impacts was applied to evaluate the methods. Another task of this work was to develop and apply the *nNIS* index, an approach for assessment of the effectiveness of the environmental policy aimed at prevention of the biological invasions. The index is based on a global information system on aquatic NIS (AquaNIS), which completes *nNIS* with data on introduction pathways, environmental tolerance limits and biological traits of these species. Also, the Mean Expansion Rate (MER) was studied as a measure of species invasiveness, which helps to distinguish between the human-mediated and natural spread of NIS. The combination of the latter two tools may be used for the implementation of the environmental policy on biological invasions, such as the International Convention for the Control and Management of Ship's Ballast Water and Sediments, the EU Regulation on Invasive Alien Species, the EU Water Framework and Marine Strategy Framework directives.

Key words

Biological invasions, non-indigenous species, EU regulation, IMO guidelines, assessment methods, expansion rate, effectiveness of prevention measures.

Reziumė

Biologinių invazijų reiškinys arba žmogaus sukeltas svetimkraščių rūšių judėjimas į naujas teritorijas, kuriose jų anksčiau nebuvo, vis labiau traukia ne tik mokslininkų, bet ir aplinkos politikos formuotojų bei pramonės atstovų dėmesį. Biologinių invazijų tyrimas tapo sudėtinga tarpdalykine mokslinių tyrimų erdve, apimančia fundamentalius ir taikomuosius aspektus. Šis tyrimas yra skirtas biologinių invazijų poveikio analizei ir rizikos vertinimo metodams, kurie reikalingi tiek teoriniams tyrimams, tiek praktiniam biologinių invazijų valdymui. Šiame darbe buvo analizuojami tarptautinių ir Europos įstatymų reikalavimai, siekiant parengti kriterijus ir vertinimo sistemą biologinių invazijų rizikos ir poveikio metodų tinkamumui įvertinti. Rizikos vertinimo sistema, kurios pagrindą sudarė pagrindiniai rizikos vertinimo principai, rizikos vertinimo komponentai ir biologinių invazijų poveikio kategorijų tipai. Vienas iš tyrimo uždavinių buvo sukurti ir pritaikyti „*nNIS*“ indeksą, kuris yra skirtas aplinkos apsaugos politikos priemonių, kuriomis siekiama užkirsti kelią biologinėms invazijoms, efektyvumui matuoti. Indeksas yra pagrįstas pasauline vandens svetimkraščių rūšių informacine sistema (AquaNIS), kur *nNIS* papildo duomenis apie šių rūšių plitimo kelius, aplinkos tolerancijos ribas ir biologines savybes. Taip pat buvo analizuojama vidutinio plitimo vertė (MER), kaip viena iš rūšių invazyvumo potencialo matų, padedanti atskirti žmonių sukeltą ir natūralų svetimkraščių rūšių plitimą. Pastarųjų dviejų priemonių derinys gali būti naudojamas įgyvendinant aplinkos apsaugos politiką, susijusią su biologinėmis invazijomis, pavyzdžiui, Tarptautinę konvenciją dėl laivų balastinio vandens ir nuosėdų kontrolės ir valdymo, ES reglamentą dėl invazinių svetimų rūšių, ES Vandens pagrindų ir Jūrų strategijos pagrindų direktyvas.

Reikšmingi žodžiai

Biologinės invazijos, svetimkraštės rūšys, ES reglamentas, Tarptautinės jūrų organizacijos gairės, vertinimo metodai, plitimo greitis, prevencinių priemonių efektyvumas.

Contents

1

Introduction

1.1 Relevance of the dissertation

The study of anthropogenic movements of organisms beyond their natural ranges began more than six decades ago, when Ch. Elton (2000) summarized knowledge about transfer of terrestrial and aquatic species in his inspiring book “Ecology of invasions of animals and plants” (1958). Since then the invasion biology became a multidisciplinary field combining fundamental (e.g. biogeography, ecophysiology, environmental genetics) and applied (e.g. environmental quality assessments, environmental low, information technologies) aspects of research (Olenin et al. 2017). Biological invasions attract increasing attention not only from scientific community (Cassey et al. 2018; Cardeccia et al. 2018; Ruhi et al. 2019; Jarić et al. 2019), but also from policy makers and various management authorities, e.g. educators, local, state, and federal agencies, nongovernmental organizations (Wilson et al. 2017; Mazaris and Katsanevakis 2018; Barney et al. 2019). This interest is due to the fact that some of the non-indigenous species (NIS) may spread rapidly, increase in numbers and cause problems to human health, economy and local environment. Such organisms, termed as invasive alien species (IAS), are a subset of established NIS, which have spread, are spreading or have potential to spread elsewhere, have an adverse effect on biological diversity, socio-economic values and/or human health in the invaded regions (Born et al. 2005; Molnar et al. 2008; Olenin et al. 2010; Bacher et al. 2018).

1. Introduction

Most environmental policies are driven by the need to preserve biological diversity, which is considered the cornerstone of healthy ecosystems (e.g. Worm et al. 2006; Uusitalo et al. 2016). Such policies are developed at the global (CBD 1992), European (e.g. Marine Strategy Framework Directive (MSFD) (EU 2008); Regulation on Invasive Alien Species, (EU 2014) and regional (e.g. Baltic Sea Action Plan, (HELCOM 2007)) levels. Some of the environmental policies are focused on the particular vectors of NIS spread, e.g. the EU Regulation on the use of alien and locally absent species in aquaculture (EU 2007) and the International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO 2007). The effectiveness of environmental policy measures in preventing unwanted biological invasions remains to be measured, since most of the early legal acts (e.g. CBD 1992) were declarative in relation to IAS, while the validity period of more specific legally binding acts (e.g. the Ballast Water Convention, IMO 2007 or EU 2014 IAS Regulation) is not sufficient to assess the long-term effect.

To support bioinvasive management, it has become necessary to develop standardized methods for assessing the state of the environment, which would have strong policy relevance (Dana et al 2014; Borja et al. 2017; Dickey et al. 2018). With the advent of the first bioinvasive impact assessment methodologies (Olenin et al. 2007; Molnar et al. 2008), a new field of applied invasion biology has begun, aimed at developing an objective measurement of the effects of bioinvasion and risk assessment (e.g. Copp 2009; Nentwig et al. 2010; Essl et al. 2011). Although the number of systems for assessing the impact of biological invasions and risk assessments is increasing, and they focus on the diverse effects of IAS on the environment, human health, the economy and the socio-cultural environment, there is no consensus on the choice of such tools for practical management and research (Mazza et al. 2014; Roy et al. 2017; González-Moreno et al. 2019).

In this study, the requirements of legislation are analyzed with the aim to develop criteria for the evaluation of the appropriateness of the bioinvasion impact and risk assessment methods. These criteria are used the comparative analysis of the above methods. Another aspect of this study is to develop an approach for assessment of the effectiveness of the environmental policy aimed at prevention of the biological invasions. This approach is based on the use of the information system which was developed in the framework of the EU funded VECTORS project (Narščius et al. 2012; Olenin et al. 2014) and now is being maintained and further advanced by the Marine Research Institute of the Klaipėda University. Thus, the present work may be defined as an applied bioinvasive research aimed at developing methods for the practical management of biological invasions.

1.2 Aim and objectives

The aim of this study is to develop the criteria for the evaluation of the relevance of the marine bioinvasion impact and risk assessment methods and an approach for assessment of the effectiveness of the environmental policy aimed at the prevention of the biological invasions.

The following objectives were raised for this work:

1. To compare the EU Invasive Alien Species Regulation (2018, No 968/2018) regarding risk assessments in relation to invasive alien species and the IMO (2007) Guidelines for Risk Assessment Under Regulation A-4 in order to develop criteria and framework for the evaluation of the bioinvasion impact and risk assessment methods;
2. To perform the comparative analysis of marine bioinvasion impact and risk assessment methods using the developed evaluation framework;
3. To develop and apply an index *nNIS* for assessment of new arrivals of non-indigenous species into the Baltic Sea region during the 2000-2009 and 2010-2018 periods;
4. To apply the "Mean Expansion Rate" method as a measure of the invasiveness of non-indigenous species and in order to distinguish between the natural and anthropogenic patterns of a spread.

1.3 Novelty

For the first time, the EU Invasive Alien Species Regulation (2018, No 968/2018) regarding risk assessments in relation to invasive alien species and the IMO (2007) Guidelines for Risk Assessment Under Regulation A-4 was performed in order to develop criteria and framework for the evaluation of the bioinvasion impact and risk assessment methods. Also, an index "New arrivals" (*nNIS*) was developed and applied to study patterns of new non-indigenous species introductions into the Baltic Sea region in the first two decades of the 21st century. The "Mean Expansion Rate" was applied for the first time in the Baltic Sea region to measure the invasiveness of the selected non-indigenous species. Based on that parameter, the difference between the natural and human-mediated spread was determined.

1.4 Scientific and applied significance of the results

The thorough analysis of the international and European legislation documents (the IMO Guidelines for Risk Assessment under Regulation A-4 (2007) and the EU Invasive Alien Species Regulation regarding risk assessments in relation to invasive alien species (2018, No 968/2018) allowed developing the criteria for the evaluation of the bioinvasion impact and risk assessment methods. The framework based on these criteria may assist in choosing the most appropriate risk and impact assessment methods for practical management of biological invasions and environmental status assessments of marine ecosystems. The development and application of the "New arrivals" *nNIS* index helped to identify the tendencies in primary introductions of non-indigenous species at the level of particular countries, the entire Baltic Sea and the larger (Baltic and North Sea) geographical region. The pathway analysis based on *nNIS* showed that "Spread from neighboring countries" and "Vessels" remains the most important reasons of non-indigenous species introductions in the Baltic Sea region. The application of the Mean Expansion Rate method showed that it can be used as the quantitative measure of invasiveness for non-indigenous species.

1.5 Scientific approval

Results of this study were presented in 7 international and 5 regional conferences and seminars:

1. Workshop on Biofouling/Hull fouling issues. Ministry of Infrastructure and Water Management Department of Water Management. Rotterdam, the Netherlands, April 2019;
2. The 12th Scientific – practical conference "Marine and coastal research". Klaipėda, Lithuania, May 2019;
3. The 11th Scientific – practical conference "Marine and coastal research". Klaipėda, Lithuania, May 2018;
4. ICES Annual science conference. Fort Lauderdale, Florida, USA, September 2017;
5. The11th Baltic Sea Science Congress "Living along gradients: past, present, future". Rostock, Germany, June 2017;
6. Seminar at Norwegian University of Science and Technology, Centre for Biodiversity Dynamics (CBD). Trondheim, Norway, November 2016;
7. The 7th Scientific – practical conference "Marine and coastal research". Klaipėda, Lithuania, May 2014;
8. The 6th Scientific – practical conference "Marine and coastal research". Klaipėda, Lithuania, May 2013;
9. The 6th international student conference. Palanga, Lithuania, October 2012;
10. The 7th European Conference on Biological invasions, NEOBIOTA 2012. Pontevedra, Spain, September 2012;
11. IEEE/OES Baltic 2012 International Symposium. Klaipėda, Lithuania, May 2012;
12. The 4th Scientific – practical conference "Marine and coastal research". Palanga, Lithuania, April 2011

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

1. **Srėbalienė G**, Olenin S, Minchin D and Narščius A (2019) A comparison of impact and risk assessment methods based on the IMO Guidelines and EU invasive alien species risk assessment frameworks. PeerJ, 7, e6965. https://doi.org/10.7717/peerj.6965

2. Solovjova S, Samuilovienė A, **Srėbalienė G**, Minchin D and Olenin S (2019) Limited success of the non-indigenous bivalve clam *Rangia cuneata* in the Lithuanian coastal waters of the Baltic Sea and the Curonian Lagoon. Oceanologia, 61: 341-349.

3. González-Moreno P, Lazzaro L, Vilà M, Preda C, Adriaens T, Bacher S, **Srėbalienė G** et al. (2019) Consistency of impact assessment protocols for non-native species. NeoBiota, 44: 1-25.

4. Uusitalo L, Blanchet H, Andersen JH, Beauchard O, **Srėbalienė G** et al. (2016) Indicator-Based Assessment of Marine Biological Diversity–Lessons from 10 Case Studies across the European Seas. Frontiers in Marine Science, 3:159. doi: 10.3389/fmars.2016.00159.

5. Olenin S, Narščius A, Gollasch S, Lehtiniemi M, Marchini A, Minchin D, **Srėbalienė G** (2016) New arrivals: an indicator for non-indigenous species introductions at different geographical scales. Frontiers in Marine Science. 3:208. doi:10.3389/fmars.2016.00208.

1.6 Thesis structure

The dissertation includes eight chapters: introduction, literature review, material and methods, results, discussion, conclusions, references and technical annex. The material is presented in 173 pages, 26 figures and 12 tables, 9 Annexes. The dissertation refers to 251 literature sources. Dissertation is written in English with an extended summary in Lithuanian language.

1.7 Acknowledgements

Most of all, I would like to express my special thanks to my supervisor Professor Sergej Olenin, you have been an inspiring mentor for me. I would like to thank you for the guidance through all these years and for allowing me to grow as a research scientist. Your inspiration, advice and criticism have been invaluable.

I would also like to thank dr. Dan Minchin and dr. Anastasija Zaiko, for their advice and support at the beginning of my PhD studies. Biggest thanks go to dr. Aleksas Narščius, for his valuable input, encouragement and inspiring, sometimes crazy discussions during the whole study period.

Many thanks to dr. Hanno Sandvik for the opportunity to visit Norwegian University of Science and Technology, Centre for Biodiversity Dynamics (CBD), for the gained knowledge on "expansion model" and warm welcoming and hosting in Trondheim.

I am thankful to dr. Marija Kataržytė, Prof. Mariusz Sopota for the thesis review and valuable advice, doctoral candidates for support, help and all the fun we had together during conferences, courses and travels.

Big hughs to my colleagues and staff from Klaipėda University, Marine Research Institute and Faculty of Marine Technology and Natural Sciences, especially to all PhD students Toma, Greta, Sabina, Donata, Donalda, Miguel, to my roommate Rasa and colleagues from a "coffee room". Special thanks go to dr. Zita Gasiūnaitė and dr. Viktorija Vaitkevičienė, Eglė Navickienė and Simona Mačiukaitė for the positive attitude and friendly working atmosphere.

I would also like to thank my beloved husband Mindaugas, for help and support, the calm and positive view, and to kids Gaivilė and Šarūnas, thank you for supporting and cheering me up.

A special thanks to my family: parents, sisters Solvita and Danguole, and mother in law for help with "babysitting" and loving support. Many thanks to my friends Lina, Agne, Kornelija, Laura. Special thanks go to friends from leisure and activities club "Liūnas", the colleagues without whom and our common activities my life would be less happy.

The current study was suported by the FP7 projects DEVOTES (2012-2016), VECTORS (2011-2015) funded jointly by the EU Seventh Framework Programme and the Research Council of Lithuania, and COMPLETE project funded under the Baltic Sea Regional Programme INTERREG (2017-2020).

1.8 Abbreviations

Abbreviation	Explanation
LME	Large marine ecosystem
MSFD	Marine Strategy Framework Directive
WFD	Water Framework Directive
NIS	Non-indigenous species
IAS	Invasive alien species
nNIS	*nNIS* is the number of new NIS in an assessment unit
RA	Risk assessment
MER	Mean expansion rate
GES	Good Environmental Status
RA	Risk assessment
BINPAS	Biological Invasion Impact / Biopollution Assessment System
AI-ISK	Aquatic Species Invasiveness Screening Kit
CIMPAL	Cumulative impacts of invasive alien species
CMIST	Canadian Marine Invasive Screening Tool
GABLIS	German–Austrian Black List Information System
GB NNRA	Full Risk Assessment Scheme for Non-native Species in Great Britain
GEIAA	Norwegian Generic Ecological Impact Assessments of Alien species
GISS	The generic impact scoring system
GISS IUCN	The generic impact scoring system including IUCN criteria
HARMONIA+	HARMONIA+
GLOTSS	Global threat scoring system
RABW	Risk assessment for exemptions from ballast water management
SBRA	Species Biofouling Risk Assessment
TRAAIS	Trinational Risk Assessment for Aquatic Alien Invasive Species
WISC	Invasive Species Impact and Prevention/Early Action Assessment Tool

2

Literature review

2.1 The study of biological invasions: from collection of facts to quantitative assessments

The movement of animals and plants by humans beyond their native ranges started in pre-historical times. Lepakoski et al. (2002) stated that inland and coastal waters have been exposed to invasions when ancient tribes and their primeval agriculture and lifestyle contributed to the spread of flora and fauna. The understanding of potential threat posed by alien invaders appeared already in the 19th century, for example, Charles Darvin wrote: the introduction of a new beast must cause in a country, before the instincts of the native inhabitants have become adapted to the strangers. However, it was a release of a book in 1958 by Charles Elton "Ecology of invasions of animals and plants" which indicated the starting point of the discipline. For example, first publications describing the threats posed by introduced species appeared in early1970s (Campbell and Ormond 1970, Schofield 1973). Since then interest in biological invasions and the number of publications and books on invasive ecology began to grow exponentially (Fig. 1).

Figure 1. The terminology of “ecology of invasion” used in books and publications (1900 – 2008) (graph source Ngram Viewer)

1 pav. „Invazijų ekologijos“ terminų naudojimas knygose ir mokslinėse publikacijose (1900 – 2008) (grafiko šaltinis Ngram Viewer)

In general, the study of biological invasions allows better understanding of the processes occurring at the level of populations, communities and ecosystems and, thus, enriches the theoretical ecology discipline (Olenin et al. 2017).

Not only the discipline has had ups and downs in various decades, and the ongoing changes in terms from “invaders” to “non-indigenous species”, from “alien” to “invasive” are still taking place, but also the various hypotheses have also changed. From the beginning the most common term in describing non-indigenous species was “alien” which was identified by Elton (1958). Occhipinti and Galil (2004) indicate that alien species can be characterized as a) established alien, b) invasive alien, c) noxious alien. Synonymous or partially synonymous with such as “adventive”, “allochthonous”, “colonist”, “exotic”, “foreign”, “immigrant”, “introduced”, “invader”, “invasive”, “neozoan”, “neozoon”, “non-indigenous”, “nonnative”, “translocated” (Occhipinti and Galil 2004) can be also used. According to another opinion, a “non-native” can be described as species transported outside their native range by direct transport, leaving species moving via unassisted dispersal as “natives” even if they are responding indirectly to anthropogenic change (Gilroy et al. 2017).

As the discipline of “ecology of invasion” is relatively recently developed the terminology still is not established. The usage of misconstrued terms is of common occurrence, unfortunately: alien, allochthonous, exotic, and introduced have been used as synonyms, as well as introduction, impact and invasion (Faasse and Moorsel 2003). Scientific community is using various terms: “nonnative species”, “exotic”, “alien”, “non-indigenous”, “invasive” (Fig. 2). In this study the following terms will be used (Fig. 2).

Humans have accelerated the spread of species around the earth. While some data are available, historical distributions are still incomplete (Copp et al. 2005), natural dispersal potential is difficult to predict over large distances (Lees and Gilroy 2014), although new methods to distinguish dispersal potential are on the development (Sandvik et al. 2013, Kamenova et al. 2017).

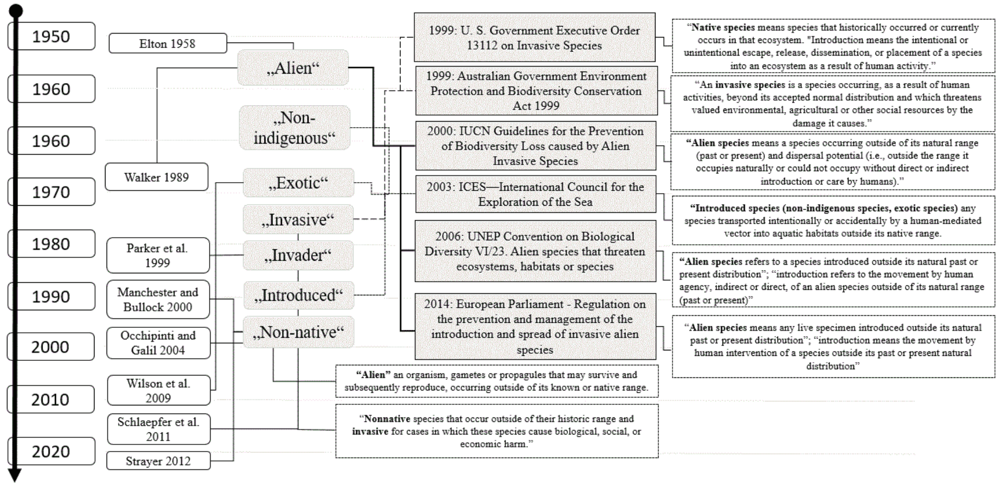


Figure 2. Terms and definitions of alien species used in literature and policy frameworks

2 pav. Svetimkraščių rūšių sąvokos ir apibrėžimai naudojami literatūroje ir politiniuose dokumentuose

While in some studies invasiveness and impact stand as synonyms, according to Ricciardi and Cohen, invasiveness and impact should not be determined as synonyms (Ricciardi and Cohen 2007). There are several definitions of the invasive species, where the invasiveness is considered as a characteristic of a species population that is spreading. The expansion of species ranges in geological and ecological time as a result of both natural and human-mediated processes, collectively referred to as biological invasions (Carlton 2001). The "invasiveness" refers to the organism's potential to colonize a large area and thus implicitly considers both its establishment and its rate of spread, while its impact is assigned according to documented effects of the invader (Ricciardi and Cohen 2007). The term "non-indigenous" represents a biogeographical category, which indicates human involvement in the introduction of certain species to a particular ecosystem (Snoeijs-Leijonmalm et al. 2017). In this study, we consider "invasiveness" as actual or potential species ability to spread.

In the last century, the study of biological invasions transformed into an interdisciplinary subject, combining fundamental and applied research of natural, technological and social sciences. Biogeography, for example, examines the origin of alien species, the processes of their transfer and resettlement in new territories; Ecophysiology studies the process of physiological adaptations of invaders in new habitats; Population biology investigates outbreaks and subsequent decreases in abundance; Functional ecology analyses the role of invaders in trophodynamic changes in ecosystems and the formation of new habitats. The applied aspects of the biological invasion discipline are ecological economics, environmental law, conservation biology environmental quality assessments. Now it is discussed more about the positive patterns of alien species, and not escalating negative effects and impacts of these species (Bax et al. 2003). Biological invasions as a study field remains a regular target of criticism – from outright deniers of the threat to scientists questioning the utility of the discipline (Courchamp et al. 2017).

One of the reasons that invasion ecology is complexed and stratified discipline, is that data are not clear and can be disapproved, the data gained during laboratory experiments can be accused of being unnatural, as for observational field data it can be protested for not revealing the cause-effect relationships (Jeschke et al. 2014). Apart from the ecological difficulties in explaining when and why species become invasive, growing concern surrounds the socioeconomic aspects of the issue (Booy et al. 2017). It seems that the most critical task in last ten years of the invasive ecology is to select way to assess the impact of invasive species on the environment, ecosystem functions and the economy in order to develop clear criteria for decision of management of alien species (Essl et al. 2011; Blackburn et al. 2014; Olenin et al. 2017). Although human activities are the main cause of biological invasions, humans also experience negative impacts of these invasions (Born et al. 2005; Ciruna et al. 2005; Marchini et al. 2015). The harm of invasive species is one of the reasons why the policy and management implications become necessary for common processes for prevention measures (Lodge et al. 2006).

In recent years' scientific community and environmental policy makers are developing and applying a set of internationally agreed indicators to assess the status of biological invasions (McGeoch et al. 2006; 2010 Olenin et al. 2016; Rabitsch et al. 2016; Latombe et al. 2017; Wilson et al. 2017); however, the use of them is still scarce, the lack of indicators stems either from lack of monitoring data or from lack of expert's time for further development.

2.2 Types of invasive alien species impacts from environment to human health

The world-wide dispersal of species has increased by orders of magnitude, and this has contributed to some regions now being invaded by several new species per year (Cohen and Carlton 1998; Reise et al. 1998; Coles et al. 1999; Hewitt et al. 2004). One of the hypotheses argues that about 10% of species established will become invasive/pest species (Williamson and Brown 1986; Jeschke et al. 2012), while other studies show that the establishment of invasive species percentage varies from 5-20% (Jeschke et al. 2014). However, all species that enter a new territory have various ways to change the environment, still a detailed analysis, with experiments and modelling, is necessary for a satisfactory explanation (Gallien et al. 2010; Bellard et al. 2014).

The impacts posed by IAS vary from negligible changes till tremendous "cascade effects" (Thomsen 2013). It is notable that same species can take different types of impacts depending on surroundings. A variety of impacts can be narrowed down to four main categories: impacts on human health, economy, environment, socio-cultural values (Molnar et al. 2008; Seebens et al. 2016; Olenin et al. 2017).

From the variety of impacts, the most undetermined ones in the sense of assessment are the impact on human health, which can be direct or indirect, posed by aquatic species. It can be human pathogen, human parasites, toxic compounds, venomous organisms, and general impact on human health (Mazza et al. 2018), as it can pose indirect impact through poisoning, parasite transmitting, and etc. The impact on economy can vary from financial losses in fisheries to expenses for cleaning intake or outflow pipes and structures from fouling (Black 2001; Williams et al. 2010).

IAS can cause environmental consequences such as the displacement of native species (Grosholz 2002), changes to community structure (Occhipinti-Ambrogi and Savini 2003) and food webs (Skora and Rzeznik 2001; David et al. 2017); expand geographical distribution (Zimmermann et al. 2010; Václavík and Meentemeyer 2012), which can result in pathogens and disease outbreaks (Crowl et al. 2008; Mazza et al. 2014). The consequences also can be evolutionary type as hybridization with native species (Allendorf et al. 2001; Coleman et al. 2014; Bouchemousse et al. 2016), population differentiation and physiological adaptation (Grosholz 2002; Strong and Ayres 2013). Each invading species is a unique case, with impacts in either freshwater, transitional (estuarine) or marine environments. Since, in the great majority of cases, reversions to the previous state are unlikely, such non-indigenous biota pose a dilemma for managers who strive to adhere to regulatory aspirations.

All levels and processes within an aquatic ecosystem can be modified by the presence and functioning of an invasive species. A new type of indicators for the assessment of water bodies' status was developed and applied during implementation of policies such as WFD (Water Framework Directive) and MSFD (Marine Strategy Framework Directive). The impacts of NIS should be considered while assessing ecological status of a waterbody and implementing water quality improvement tools and programs (Cardoso and Free 2008; Orendt et al. 2009; Uusitalo et al. 2016). As NIS are able to cause changes in the ecological status of a waterbody and consequently change the water quality parameters used in the WFD. Impacts on biological, physico-chemical and hydro-morphological quality elements identified in the literature are summarized in Figure 3.

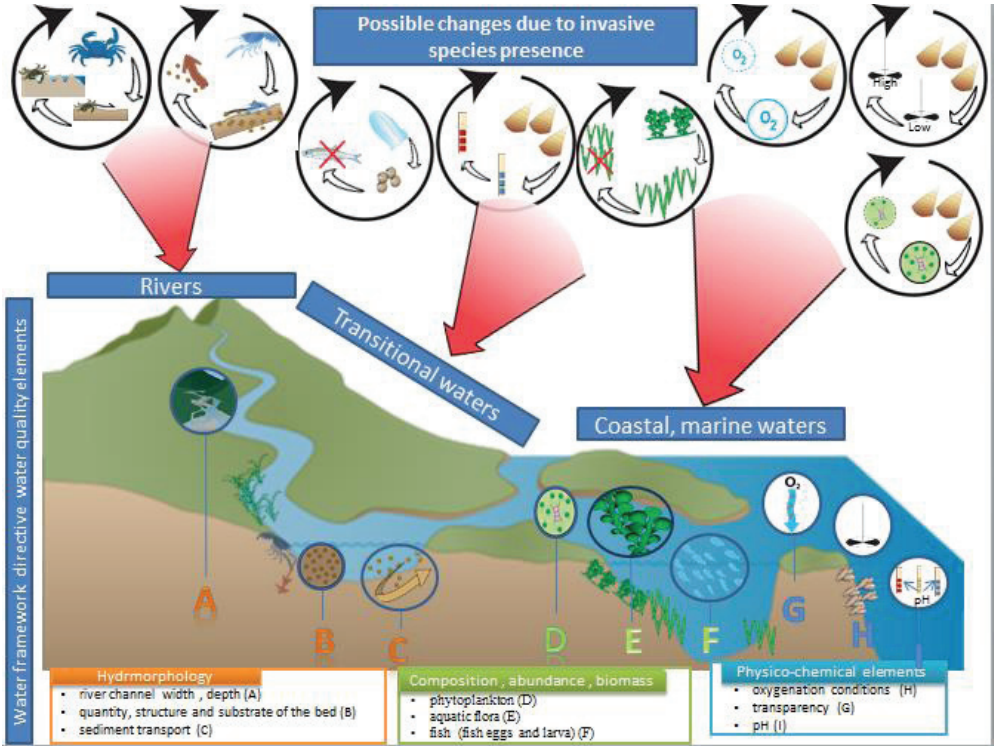


Figure 3. Possible impacts on environment by invasive species

3 pav. Invazinių rūšių poveikis gamtinei aplinkai

Taking as an example the Ireland and the United Kingdom which have incorporated alien species pressures explicitly in their WFD status assessments, a guidance document on this issue was produced (UK TAG 2004). These documents are accompanied by the list of NIS, categorized according to the impact, which are used in WFD risk assessment and for the downgrading ecological status according to the alien species pressure. A similar approach is being used by Catalonia in high mountain lakes, where downgrading follows introduction of fish species (Benejam et al. 2008). Alien species are included into multimetric index to assess the ecological status of Basque estuaries (Borja et al. 2004; 2005).

In Belgium, WFD fish metrics evaluate the proportion of alien species biomass in lakes and certain river zones (Breine et al. 2004). Germany has developed a tool to assess the status of large rivers, where lower scores are attributed the rivers with alien species (Meilinger et al. 2005). Sometimes NIS are removed from reference communities when assessing the status of benthic communities in coastal and transitional waters by means of the Benthos Ecosystem Quality Index (Van Hoey et al. 2007) and of rivers in the Austrian Fish Index (Gassner et al. 2005). A correct understanding of pressure-impact relationships is vital for the successful implementation of the aquatic and marine policies (IMPRESS 2003).

2.3 Review of the biological invasion risk and impact assessment methods

The main task of the biological invasion risk and impact assessment methods is to evaluate the impact processes and consequences (Essl et al. 2011). There are features that should be included in assessment methods, some features are species-specific (Roy et al. 2017). Measuring the impact on ecosystems and invasion potential is important due to management prevention of IAS.

More than seventy tools have been developed during recent decades aimed at bioinvasion impact and risk assessment (Roy et al. 2017). They are named variously as “protocol” (Verbrugge et al. 2012), “framework” (Dahlstrom et al. 2011), “tool” (e.g. Drolet et al. 2016), “kit” (e.g. Copp et al. 2009), “scheme” (e.g. Baker et al. 2008), “system” (e.g. Nentwig et al. 2010), “index” (Olenin et al. 2007), etc. In this study, we have termed these as “bioinvasion risk and impact assessment methods”, or “the methods”. Some methods measure the risk as likelihood of establishment (and also dispersal, spread or having impact) while others assess the impact magnitude. Methods may differ according to the geographical scale from local to regional and global, and by realm, either terrestrial or aquatic, or both. The principal aim of these methods is to provide information to support management decision by prioritizing invasive species, choosing prevention measures, compiling target lists and assessing their overall environmental status (Olenin et al. 2007; Molnar et al. 2008). While the number of methods increases, there are difficulties in choosing the most appropriate method that best corresponds to the basic principles of risk assessment (RA). The need for standardized methods to measure the magnitude of invasive species impacts and risks has promoted a new direction in applied invasion ecology (Marchini et al. 2015; González-Moreno et al. 2019). There was a couple of attempts to standardize and explore all risk assessment methods, but no common standard has emerged (Essl et al. 2011; Turbe et al. 2017).

Some international legislation and administrative documents provide guidelines and methodologies for measuring bioinvasion risk and impact assessment methods (Dahlstrom et al. 2011; Verbrugge et al. 2012; Tollington et al. 2017). For example, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWMC) aimed at reducing the spread of harmful aquatic organisms and pathogens (HAOPs)

(IMO, 2004). Later the IMO developed Guidelines for risk assessment outlining methods enabling managers to identify the risk scenarios and take decisions on granting ballast water management exemptions under BWMC Regulation A-4 (G7) (IMO 2007), which came into force in September 2017 (IMO 2017), assessment guidelines, which offer three types of risk and impact assessment: environmental matching, species biogeographical, and species-specific risk assessment.

Bearing in mind that each vessel carrying ballast water is a potential risk (David and Perkovič 2004), then we need appropriate tools to assess it and to distinguish between high and low risk (acceptable/unacceptable risk/impact). Barry et al. (2008) reviewed eight "ballast water risk assessment systems" developed from 1992 to 2004. Later, David and Gollasch et al. (2015) completed a review including four additional methods and assessed their compliance with the BWMC requirements. However, since then, new methods for ballast water RA (e.g. Drolet et al. 2016, Verna et al. 2016; Simard et al. 2017) and the updates of earlier reviewed methods have appeared (e.g. David and Gollasch et al. 2015). Dahlstrom et al. (2011) took a more general approach assessing the "biosecurity risk assessment frameworks" based on fourteen international, regional and national legal instruments. They proposed a set of recommendations to develop aquatic biosecurity risk frameworks in accordance with the mandates established by international bodies.

Similarly, at the European level, the EU Parliament adopted the Regulation on the prevention and management of the introduction and spread of invasive alien species (IAS) (EU 2014), and a few years later, it provided a supplementary document with regard to IAS risk assessment (EU 2018). With the advent of the EU Regulation (EU 2018), there is a need for an approach that enables the comparison of the different bioinvasion risk and impact assessment methods, and also ensures their compliance with legislative and administrative requirements. As there is an increase in need to monitor progress and assess the effectiveness and impact of policies (Gallopin 1996) in order to do this we require criteria and indicators which will allow doing so.

Most of the impact and risk assessment methods are legally not binding, so the enforcement of their results in NIS management is limited. Some systems are confirmed and used by regional organizations (e.g. HELCOM) such as like Biological pollution index (Olenin et al. 2007). Most of the methods concentrate on and assess the environmental properties; non-less important is human health and economic categories. The impacts on infrastructure, tourism and recreation activities, aesthetics, and other issues are still lacking. In order to improve the integration of these categories of very diverse domains they should be framed in a common risk analysis framework (D'hondt et al. 2015).

The structure of most methods can be divided into basic blocks like predicting the risk that a species will be transported and introduced, the status of establishment, increase in abundance and spread and cause impacts. Basically, for the perfect impact and risk assessment methods attributes should follow the framework of the typical invasion processes: transportation, introduction, establishment, spread, adaptation and impacts (Fig. 4).

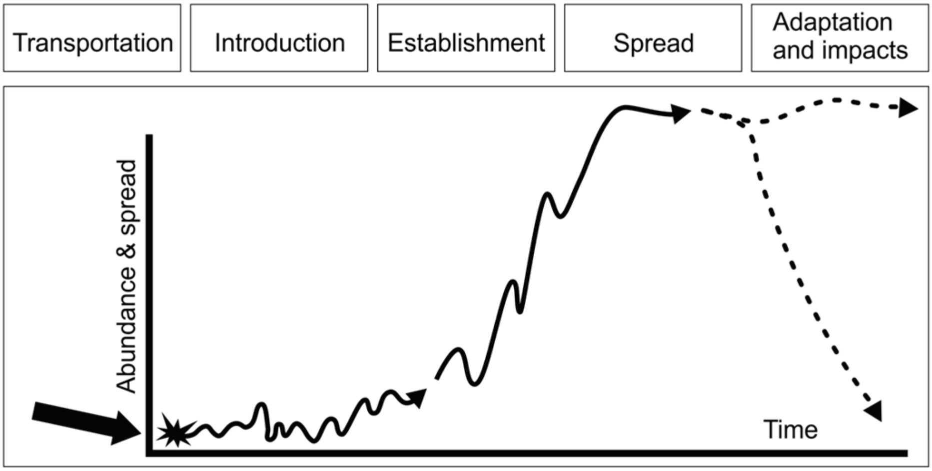


Figure 4. A typical invasion sequence (according to Reise et al. 2006)

4 pav. Tipinė invazijų plitimo kreivė (sudarė Reise et al. 2006)

It is difficult to measure the magnitude due to the scarcity of information for most species and the outcomes of introductions may be spatially and temporally context specific (Leung et al. 2012). The need to improve the ability to detect and report new incursions of IAS into Europe promptly is widely recognized by policy-makers, statutory bodies, researchers and many other stakeholders.

Different stakeholders and managers expect various results while using risk and impact assessment methods: what environment elements are impacted? What is the magnitude of impact using standard measures? What kind of consequences will it have to regional economies? The main goal of the assessment for stakeholders is a clear message what and where to prevent and act. Risk and impact assessment methods may include main threats that are incorporated in different frameworks (CBD (1992), WFD (2000), BWMC (2004), MSFD (2008)), national or regional strategies.

Underpinning this there is the need to establish effective pan-European information systems for sharing NIS information with neighboring countries (European and not European), trading partners and regions with similar ecosystems, particularly those of high conservation status. This would help to facilitate the identification, the early warning and coordination of prevention, the mitigation and restoration measures. Such an information system should assist in locating, documenting and providing electronic access to sources of information, provide quality control and ensure controlled, agreed and shared (harmonized) terminology.

The review of methods currently used to assess IAS impacts reveals that assessments can depend on the expert judgment. This can be seen as an advantage, e.g. by the use of state-of-the-art knowledge which can be adapted when pre-invasive state is unavailable. It can also be regarded as a disadvantage, because it is not clear how experts arrive to their judgments. It is also mentioned that if the assessment relies on expert knowledge solely, the reproducibility and hence the stability of the assessment are limited (Essl et al. 2011). This drawback can be overcome by using a standardized method (De Lange and Wilgen 2010). The taxonomical diversity of IAS is also a big challenge for experts, as most of the assessment methods are effective only using one taxonomic group. Impact and risk assessment methods should be very adaptive and quantitative and generic in an economical and environmental manner. Also method should be transparent, repeatable and testable (Sandvik et al. 2013).

2.4 Policy and legislation on marine biological invasions

Chemical-pollution and organism-based pollution should be considered in the same way, according to Elliott (2003). Despite the differences between chemical and biological pollutants, the impact detection remains the same and attempts to detect a signal to noise ratio have the same philosophy (Elliott 2003). For example, chemical origin pollution such as oil spills at sea may cause damage to the environment, but with time, the oil evaporates and impacts generally become reduced, while the environmental impacts associated with NIS and when the organisms become established, the consequences to native communities may be widespread, irreversible and the impact significantly greater than minor or transitory (Hughes and Convey 2014)

After the introduction of NIS into a new environment, while planning and implementing management options, the patterns of different stages of invasion should be taken in mind (Wittenberg and Cock 2001; Lodge et al. 2006; Davis 2009; Minchin et al. 2009). The prevention of introductions involving inspection, exclusion and/or primary treatment is only possible early in the process, before a species arrives at the point of entry (Olenin et al. 2011). A new arrival of NIS may prevent further invasion due to a rapid response (e.g. eradication, quarantine). However, if NIS is established its eradication is costly and sometimes hardly possible, it mainly depends on a rapid response by the managers. The secondary spread from an area of primary introduction due to natural dispersal and/or human mediated vectors may obstruct an effective management option (Olenin et al. 2011).

Since 1992, when in Rio de Janeiro the Convention on Biodiversity by United Nations was signed, an invasive species was identified as threats to biodiversity (Keane and Crawley 2002; OECD 96). Following the Convention on Biodiversity (CBD) the main focus for alien species is species whose introduction and spread threatens ecosystems, habitats or species with socio-cultural, economic and/or environmental harm, and/or harm to human health" (COP 2002). The Convention on Biological Diversity (CBD 1992) sets an ambitious goal to "prevent the introduction of, control or eradicate alien species which threaten local or regional biodiversity".

Recently, legally binding and advisory instruments, aimed at reducing the spread of NIS species by particular vectors of introduction came into force. For example, the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWMC) (IMO 2004) came into force in September 2018 (IMO 2018). Another instrument is the Code of Practice on the Introductions and Transfers of Marine Organisms by the International Council for the Exploration of the Sea (ICES 2005; Gollasch 2007). There are numerous regional multi-lateral conventions, and agreements in place that address the issues of aquatic bioinvasions, such as the Barcelona Convention (Mediterranean Sea), the Helsinki Commission (Baltic Sea), the OSPAR Commission (North-East Atlantic including the North Sea), the UNEP regional Seas programs, the South Pacific Regional Environmental Program, and the Asia-Pacific Economic Cooperation (Hewitt et al. 2009). Also, several nations have established regulatory frameworks for the prevention and management of intentional and accidental bioinvasions, for example, the US Invasive Species Act, the Biosecurity Act of New Zealand (Hewitt et al. 2009). At the European level, the EU Regulation on the Prevention and Management of the Introduction and Spread of Invasive Alien Species (2014) was adopted, indicating the prevention as the main target: "*the prevention is generally more environmentally desirable and cost-effective than reaction after the fact, and should be prioritized*". All the above legal and administrative, global and regional instruments require a robust, scientifically sound indicator(s) to measure their effectiveness in terms of reducing unwanted invasions. For example, the European Environment Agency (EEA) proposed an indicator "*Cumulative numbers of alien species in Europe since 1900*" to measure progress towards achieving the CBD goal (EEA 2007). Counts from different countries were assigned to decades, data were provided by national authorities (EEA 2012).

The Marine Strategy Framework Directive (MSFD, 2008/56/EC) includes within the 11 qualitative descriptors the non-indigenous Species (NIS) as one of the elements to be assessed to determine if an ecoregion is in good environmental status or not. To assess it, the European Commission (2010) proposed a series of indicators which include "*Trends in abundance, temporal occurrence and spatial distribution in the wild of non-indigenous species*", similar to the CBD indicator by EEA (2007), which was used by most Contracting Parties in their initial environment status assessments for the MSFD (ICES WGITMO 2016).

An elevated number of NIS generally indicates a greater level of exposure of a marine area to anthropogenic activity (Olenin et al. 2010). Whether, or not, NIS become established is only partly related to the environmental status of an area; and it also depends on biological traits of the species (e.g. Cardeccia et al. 2018), integrity of native ecosystems (Didham et al. 2005) and availability of resources (Davis 2009). The "*Cumulative number of NIS*" is of lesser importance for the management than the "*Number of species transferred by a vector(s)*", which aids any practical prioritization of preventive measures. This is because the taxonomic knowledge was incomplete for many early introductions and records were seldom kept (Carlton 2009), also the presence of NIS often remained unnoticed until they will have become obvious and created some nuisance impact (Olenin and Minchin 2011). As it was shown in a recent regional overview (Ojaveer et al. 2018), even in a marine region with a long history of biodiversity research, such as the Baltic Sea, where due to natural circumstances and recent geological history, species richness is low and any new arrival is likely to be more visible than elsewhere, there is a weak availability of introduction event records from before the 1950s (Olenin et al. 2016).

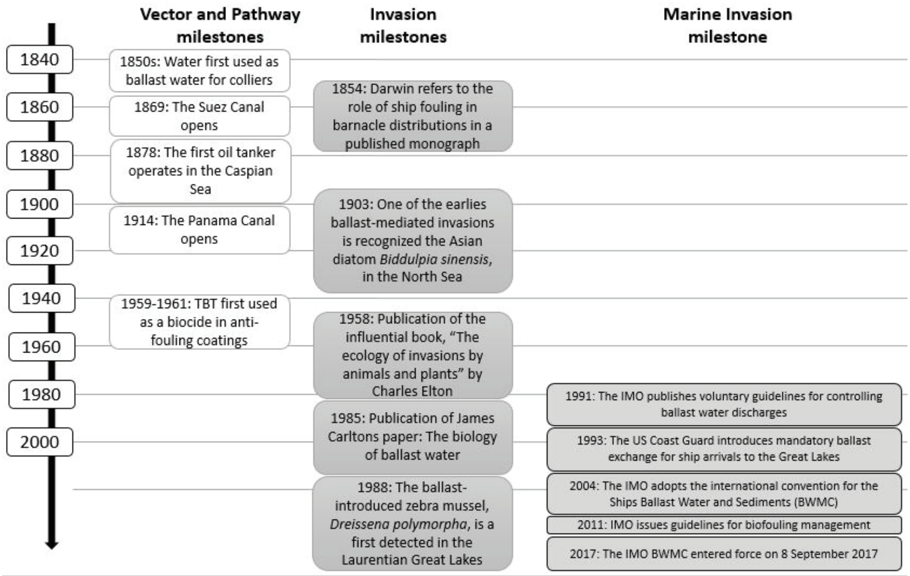


Figure 5. Development of marine policy in sense of biological invasions (according Davidson et al. 2018)

5 pav. Jūrų politikos vystymąsis biologinių invazijų atžvilgiu (pagal Davidson et al. 2018)

2.5 Information support for biological invasion management

Databases could be a good tool for information support for biological invasion management. The availability of data from local to global scales is crucial to deal with the issues affecting society (Costello 2009). Scientific databases are increasingly being used for the research. Data provided by scientific papers and databases can be the foundation of science, with the interpretation of these facts leading to information and theories that create knowledge (Costello and Vanden Berghe 2006). For instance, an observation system that collects data on species abundance for several taxa at multiple locations on our planet can support the derivation of the Living Planet Index (Collen et al. 2009), the Wild Bird Index (Butchart et al. 2010), the Community Temperature Index (Devictor et al. 2012), measures of species range shifts (Parmesan 2006), and a number of other high-level indicators is widely used for the governmental and environmental assessments for policy application, e.g. CBD's indicative list of indicators for the strategic plan for biodiversity 2011 – 2020 (CBD 2015).

During the last decade the information derived from these on-line sources was used in the peer-reviewed literature to: compose NIS lists for specific areas (e.g. Gollasch and Nehring 2006; Zaiko et al. 2007; Westphal et al. 2008; Occhipinti-Ambrogi et al. 2011), prioritize NIS according to impact (e.g. Cambray 2003; Olenina et al. 2010; Savini et al. 2010), identify and quantify the ecological impacts of specific taxa or functional groups (e.g. Butchart 2008; Vilà et al. 2009; Occhipinti-Ambrogi and Galil 2010; Kuebbing et al. 2013), define pathways and vectors responsible for introductions (e.g. Gollasch 2006; Hulme et al. 2008; Marchini et al. 2008; Minchin et al. 2009; Savini et al. 2008, 2010; Galil 2012), analyze species traits and ecological preferences (e.g. Prinzing et al. 2002; Paavola et al. 2005; Strayer 2010), assess the risks posed by NIS species on economies and ecosystem services (e.g. Occhipinti-Ambrogi 2000; Baker et al. 2005; Campbell et al. 2008; Diederik et al. 2011), assess the risk of certain NIS introduction vectors (e.g. Gollasch et al. 2011), and provide recommendations for management measures (e.g. Casal 2006; Olenin et al. 2011; Wilgen et al. 2012).

The need and importance of such biological invasion database was stressed at the European Strategy on Invasive Species (Genovesi and Shine 2004). It was noted that the information sharing between states and scientific institutions is a critical factor for the prevention, both of new arrivals and spread of introduced aliens (Drake and Lodge 2006). The knowledge-base on non-indigenous species continuously expands and so the number and availability of web resources on NIS are rising (Olenin et al. 2014).

Beginning from 1997 the platform of the first database in Europe called the Baltic Sea Alien Species Database (Olenin et al. 2002; 2007) which was widely accepted between scientific community (e.g. Baltic marine biologists) and governmental institutions (HELCOM) was formed. At European scale the DAISIE (Delivering Alien Invasive Species Inventories for Europe) project was the first attempt to gather data on NIS in Europe. Online systems were built on the global scale such as the Global Invasive Species Database (GISD 2007) managed by the IUCN Species Survival Commission Invasive Species Specialist Group (ISSG) containing the information on the ecology of alien species (Latombe et al. 2017).

Currently there are more than 250 websites on NIS worldwide (GISIN 2013). The geographical area of these information resources varies from global (e.g. GISD 2013) to national (e.g. Mastitsky et al. 2012; Nehring 2013). Many of these databases began as inventories of

NIS, but evolved to include keys for NIS identification, donor and origin regions, introduction histories, pathways, vectors, etc. (Olenin et al. 2014). Although, it should be stressed out that the product of the network must also be sufficiently unique, of appropriate size, quality assured, and thus prestigious, that host institutions, with long-term support (Costello et al. 2014). More systems such as Marine Invader Tracking Information System (MITIS 2007), National Institute of Invasive Species Science database (NIISS 2007), USGS Nonindigenous Aquatic Species information resource (USGS NAS 2007), NEMESIS in USA, in Europe EANIS (Katsanevakis et al. 2012) and AquaNIS (Olenin et al. 2013).

The existing databases provide various research and management objectives, most of them store and provide data on species locations and distributions (EANIS, AquaNIS), species information (GISD), general species lists, some of them track the control of NIS (MITIS) (Crall et al. 2006).

AquaNIS is an online database on the aquatic Non-Indigenous Species, and species, which might be considered as NIS, i.e. cryptogenic species (AquaNIS 2019). The aim of the system is to store and disseminate information on NIS introduction histories, recipient regions, taxonomy, biological traits, impacts, and other relevant data. The system contains data on NIS introduced to marine, brackish and coastal freshwater waters of Europe and neighbouring regions.

AquaNIS ensures the long-term maintenance and reliability of the database by continuous update and scientific validation of its data. The content of the system is a usable tool in relation to the aquatic systems legislative documents, and management of the Ballast Water Management Convention, EU Water Framework Directive, The Marine Strategy Framework Directive, Risk Assessment measures. A special attention is paid to different pathways, especially shipping and aquaculture. The database is constantly updated with new records. All entered data is checked as far as it is possible to current taxonomic status and references are supplied to qualify each of the datasets (Olenin et al. 2014).

AquaNIS contains data on more than 1740 aquatic NIS and CS in 50 recipient regions in Europe and neighbouring areas. The NIS list represents a broad spectrum of free-living and parasitic multicellular and unicellular organisms including 34 phyla, 68 classes, 187 orders, 515 families and 851 genera. These numbers are revised with the inclusion of newly recorded NIS and their spread into new regions, with changes to their nomenclature and taxonomy. Because of the dynamic nature of the database, the species numbers, figures and all other calculated outputs are changing, so reflecting the level of the present knowledge. All geographic information is arranged in a hierarchical order ranging from oceans, ocean sub-regions, LMEs, sub-regions of LMEs to smaller entities, such as ports (Olenin et al. 2014; AquaNIS 2019), countries are linked to relevant LMEs or LME sub regions.

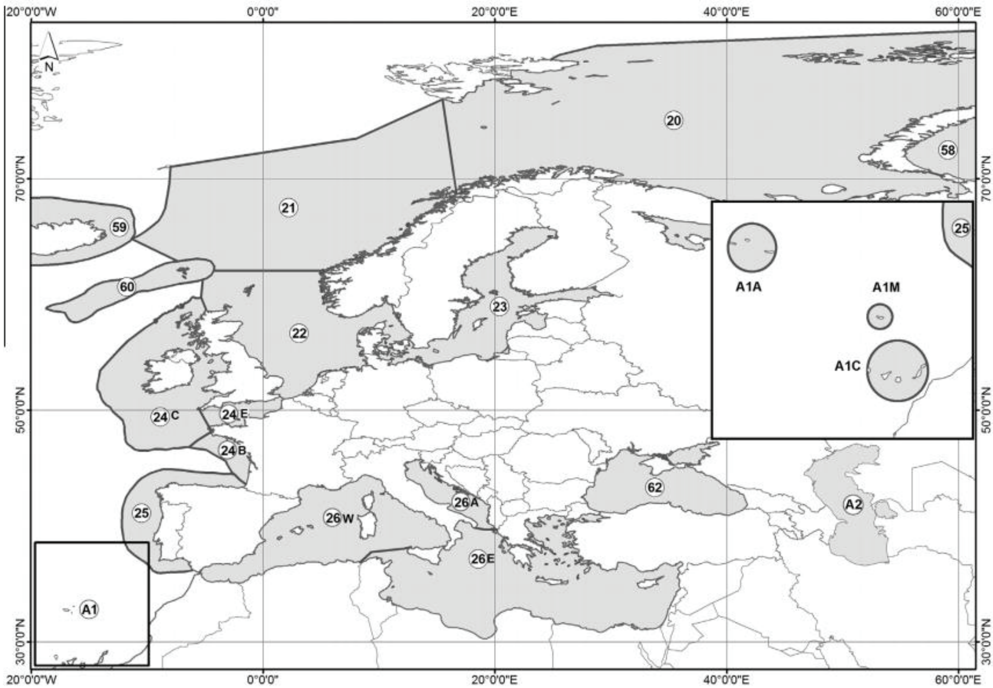


Figure 6. Large Marine Ecosystems (LMEs) and LME sub-regions. Numbers in open circles indicate Large Marine Ecosystems: 20 – Barents Sea; 21 – Norwegian Sea; 22 – North Sea; 23 – Baltic Sea; 24 – Celtic-Biscay Shelf with sub-regions (24C – Celtic seas, 24E – English Channel, 24B – Biscay); 25 – Iberian Coastal; 26 – Mediterranean Sea with sub-regions (26W – Western Med, 26A – Adriatic Sea, 26E – Eastern Med); 59. Iceland Shelf; 60 – Faroe Plateau; 62 – Black Sea. Additional LME-like regions: A1 – Macaronesia with sub-regions (A1A – Azores, A1M – Madeira, A1C – Canary Islands); A2 – Caspian Sea (Olenin et al. 2014).

6 pav. Didžiosios jūrų ekosistemos (DJE) ir DJE subregionai. Skaičiai apskritimuose nurodo DJE: 20 – Barenco jūra; 21 – Norvegijos jūra; 22 – Šiaurės jūra; 23 – Baltijos jūra; 24 – Keltų – Biskajos subregionas (24C – Keltų jūra, 24E – Lamanšo sąsiauris, 24B – Biskajos įlanka); 25 – Iberijos pakrantės; 26 – Viduržemio jūra ir subregionai (26W – Vakarinė Viduržemio jūros dalis, 26A – Adrijos jūra, 26E – Rytinė Viduržemio jūros dalis); 59. Islandijos šelfas; 60 – Farerų plynaukštė; 62 – Juodoji jūra. Papildomi DJE regionai: A1 – Makaronezija ir subregionai (A1A – Azorų salos, A1M – Madeiros, A1C – Kanarų salos); A2 – Kaspijos jūra (Olenin ir kt. 2014).

2.6 Summary of the literature review

A brief review shows that literature on the human-mediated movement of organism impacts over the borders of biogeographical regions is growing exponentially. The invasion biology, which started six decades ago, now has become a multidisciplinary research area with clearly defined applied, practical tasks. The impacts of NIS are multiple and include a broad spectrum of effects on environment, economy, human health and socio-cultural values important for human society. The environmental policy aimed at minimising risk of IAS introduction requires scientific support and robust impact and risk assessment methods. The number of such methods is growing and therefore there is a need in the development of methodology for their evaluation. Some aspects of the invasion process such as “invasiveness” still need quantification. Indicators are also needed to measure the effectiveness of environmental policy aimed at prevention of NIS. Thus, the current PhD thesis is addressed to the above mentioned research needs, taking into account the applied aspects of invasion biology.

3

Materials and methods

3.1 Comparison of risk and impact assessment methods

3.1.1 Setting criteria for evaluation based by policy frameworks

The two RA frameworks of the IMO (2007) and EU (2018) regulations were compared in order to provide a methodological support for a common evaluation procedure (for details see Fig. 7). Accordingly, the RA frameworks were screened as follows: (i) key principles of an assessment process, (ii) assessment components and, (iii) categories of bio-invasion impacts to be taken into account using the above RA frameworks.

The IMO Guidelines define the key principles (effectiveness, transparency, consistency, comprehensiveness, risk management, precautionary, science-based, continuous improvement) that should be taken into account in a RA. The EU Regulation mentions the RA principles, but not explicitly as in the IMO guidelines. As a result, the evaluation is based on the eight principles listed in the IMO Guidelines. The IMO Guidelines define three approaches of RA: environmental matching (i), biogeographical (ii) and species-specific (iii).

For the "*environmental matching*", according the Convention, methods should explicitly take into account the comparison of environmental conditions such as salinity, temperature, indication of likelihood of survival and establishment and the comparison of environmental conditions in order to assess the degree of similarity between risk and impact assessment methods (David et al. 2013; Liu et al. 2014).

For the "*biogeographical risk*" approach, methods should consider the number of records of NIS in region and compare the numbers of IAS with native species in the introduction areas. We have taken into account only those methods that consider the aspects of records on species distribution outside native region.

For the third approach, "species specific" the methods should take into account information on life history and physiological tolerances in order to estimate species potential to survive or complete its life cycle in the recipient environment, the damage to the environment, threats to human health, property or resources.

All these approaches are reflected in the eight articles outlining RA compartments in the EU Regulation. However, the IMO guidelines have no direct matching with the two equivalent articles in the EU Regulation (*Art 5(1)(g)* and *Art 5(1)(h))* (Annex 3); and only partial reference to the six other articles. Furthermore, the EU Regulation gives a brief description of compartments that need to be addressed in RA methodologies. Based on this study we included all 29 RA components of the EU Regulation into an evaluation procedure. The IMO Guidelines mention four impacts: "*on environment, economy, human health, property or resources*" (IMO 2007). The EU Regulations include five impacts "*on biodiversity and related ecosystem services, including on native species, protected sites, endangered habitats, as well as on human health, safety, and the economy including an assessment of the potential future impact*" (EU 2018). We narrowed down the impacts referred to in both documents to four principal types: a) human health, b) economy, c) environment (incl. biodiversity and ecosystem services), and d) social-cultural values.

3.1.2 The evaluation procedure

Based on the comparison of the IMO Guidelines and the EU Regulation, the evaluation procedure included eight key principles of the IMO Guidelines, twenty-nine RA components of the EU Regulation and four main bioinvasion impact types, compiled from both documents (see Fig. 7). In addition, impact categories as proposed in the earlier risk assessment frameworks were incorporated (Emerton and Howard

2008; David and Gollasch 2015; Olenin et al. 2016; Vilà and Hulme 2017). Totally, 41 categories were defined: human health (6 categories), economy (11), environment (20), social-cultural aspects (4) (Table 1). Descriptions of the impact categories are provided in the Annex 1.

Table 1. **Impact categories used in risk assessment frameworks: human health (6 categories), economy (11), environment (20), social-cultural aspects (4).**

1 lentelė. **Poveikio kategorijos taikytinos rizikos vertinimo sistemose: žmonių sveikata (6 kategorijos), ekonomika (11), aplinka (20), socialiniai ir kultūriniai aspektai (4).**

Impact types	Categories	Impact types	Categories
Social and cultural	Recreation and tourism locations	**Environment**	Parasite on native species
	Education and research		Predation
	Spiritual and religious locations		Hybridization
	Interference with monitoring		Parasite vector
Economical	General management costs		Habitat change or loss
	Fisheries		Competition
	Aquaculture		Pathogen on native species
	Changes to wildlife habitat		Food web changes
	Cost of changes to environment		Nutrient regime alterations
	Irrigation and abstraction		Biodiversity alteration
	Navigation		Pathogen vector
	Tourism		Herbivory/grazing
	Health care costs		General ecosystem services
	Biotechnology		Keystone species
	Opportunity costs		Threatened or endangered species
Human health	Human pathogen		Toxicity on native species
	Human parasites		Species abundance
	General impact		Pest vector
	Toxic to human		Pest on native species
	Poisoning to human		Hydrological cycle changes
	Venomous organisms		

We developed a scoring scheme in order to assess the compliance with each of the eight key principles (Table 2). The RA components and the categories of impact were considered to be either present or absent based on the original description of the selected method. The overall ranking of the methods is based on an accumulated score, and expressed as a percentage of compliance with our selected criteria.

Table 2. **A scoring system to assess the compliance to the key principles of the risk assessment: “1” the method fully meets a criterion, “0” the method is not relevant.**

2 lentelė. **Vertinimo sistema skirta pagrindinių rizikos vertinimo principų atitikimų nustatymui: „1“ - metodas visiškai atitinka kriterijų, „0“- metodas nėra svarbus.**

Key principle	Definition by IMO (2007)	Scoring criteria	
Effectiveness	*That risk assessments accurately measure the risks to the extent necessary to achieve an appropriate level of protection.*	1	definitions of all parameters provided, the calculation scheme is clear, the result is obtained either automatically using an online platform or by a questionnaire.
		0	not compliant.
Transparency	*That the reasoning and evidence supporting the action recommended by risk assessments, and areas of uncertainty (and their possible consequences to those recommendations), are clearly documented and made available to decision-makers.*	1	the reasoning and evidence supporting the assessment is documented and (or) is available via a free online information system or on request from the authors.
		0	not compliant.
Consistency	*That risk assessments achieve a uniform high level of performance, using a common process and methodology.*	1	the consistency of a method was tested by assessing the repeatability of the test outcome, the results are published in peer-reviewed literature.
		0	the assessment of the consistency of a method is not available publically.
Comprehensiveness	*That the full range of values, including economic, environmental, social and cultural, are considered when assessing risks and making recommendations.*	1	the method considers all four categories of risks and impacts (human health, economic, environmental /ecological, social and cultural aspects).
		0	a method considers less than four categories.
Risk management	*That low risk scenarios may exist, but zero risk is not obtainable, and as such risk should be managed by determining the acceptable level of risk in each instance.*	1	the method clearly defines the level of risk /bioinvasion impact that can be used for the risk management.
		0	no definition of the magnitude of risk /bioinvasion impact is given.

Key principle	Definition by IMO (2007)	Scoring criteria	
Precautionary	*That risk assessments incorporate a level of precaution when making assumptions, and making recommendations, to account for uncertainty, unreliability, and inadequacy of information. The absence of, or uncertainty in, any information should therefore be considered an indicator of potential risk.*	1	incorporates level of confidence for all risk assessment steps, including the level of confidence for the final risk score, clear instructions how to define uncertainty.
		0	no level of confidence is taken into account.
Science-based	*That risk assessments are based on the best available information that has been collected and analyzed using scientific methods.*	1	at least a part of the assessment requires quantitative experimental and/or field study data, or the review of scientific literature.
		0	the method takes into account impacts and risks of invasive species based only on expert judgement, no quantitative experimental and/or field studies data used.
Continuous improvement	*Any risk model should be periodically reviewed and updated to account for improved understanding.*	1	the method has been updated since the publication of the original version.
		0	only original version exists, has no updated version until know.

The RA components and the categories of impact were considered to be either present or absent based on the original description of the selected methods. In case the compliance of each of the selected methods, for the key principles, required confirmation by published data a literature search was performed using open source platforms (scholar.google.com and researchgate.net).

3.1.3 Selection of the bioinvasion impact and risk assessment methods

To select the bioinvasion impact and risk assessment methods for the analysis we used the list of the most relevant methods identified by Roy et al. (2017) and the COST Action Alien Challenge TD1209. They performed a worldwide literature search for the methods of invasive species risk assessment (RA), and cross-checked the references for additional relevant publications to obtain twenty-nine original RA methods.

These methods were used for the analysis based on the following criteria: (a) the method is applicable for the aquatic realm; (b) the assessment results are either in a quantitative or in qualitative form, and (c) it takes into account at least one of the four categories of bioinvasion impacts. From this preliminary analysis nine methods out of the 29 reviewed by Roy et al. (2017) were selected. Additionally, we searched the literature to include any further methods which were not considered relevant in their review, yet met the set criteria. Fifteen methods were found suitable for the analysis (Table 3). The selected methods represent different regions, however it should be noticed that there might be further methods worldwide, which could be included into analysis in the future. It should be noted that the main goal was to test the evaluation procedure on a sufficient number of methods.

Each method in this study were referred by an acronym (Table 3), while some have changed their names with further development, for example, AS-ISK (Copp et al. 2016) was originally known as FISK "Fish Invasiveness Screening Kit" (Copp et al. 2009) and the Biopollution level (BPL) (Olenin et al. 2007) was later computerized and renamed as the Bioinvasion impact/ Biopollution assessment system, BINPAS (Narščius et al. 2012). Most of the methods (75%) were published in peer-reviewed journals, one as a book chapter, and three appeared in national or international environmental reports. The methods were divided into three groups, according to their assessment goals as: (1) the screening tools (AS-ISK, CMIST, HARMONIA+), (2) risk assessment tools (GB NNRA, TRAAIS, SBRA, WISC, RABW), (3) impact assessment indexes/schemes (CIMPAL, BINPAS, GISS, GABLIS, GEIAA, GISS IUCN, GLOTSS).

Most of the analyzed methods were developed between 2007 until 2016, and some are still in the development process. The evaluation of general characteristics of methods was based on key publications. In total 15 risk and impact assessment methods were assessed using 78 criteria based on the analysis of two legislative documents and 40 research papers.

Table 3. **Summary of the risk and impact assessment methods**.

3 lentelė. **Rizikos ir poveikio vertinimo metodų suvestinė.**

Title of the method	Acronym	Key reference	Assessment goal	Method assessment	Example of the use
Aquatic Species Invasiveness Screening Kit	AS-ISK	Copp et al. 2016	Screening / horizon scanning	Excel sheet	Tricarico et al. 2010; Papavlasopoulou et al. 2014
Biological Invasion Impact / Biopollution Assessment System	BINPAS	Olenin et al. 2007	Impact assessment	Online tool	Olenina et al. 2010; Zaiko et al. 2011; Minchin and White 2014
Cumulative impacts of invasive alien species	CIMPAL	Katsanevakis et al. 2016	Impact assessment	Excel sheet	Katsanevakis et al. 2016
Canadian Marine Invasive Screening Tool	CMIST	Drolet et al. 2016	Impact assessment/ screening tool	Online tool	Drolet et al. 2016

Title of the method	Acronym	Key reference	Assessment goal	Method assessment	Example of the use
German–Austrian Black List Information System	GABLIS	Essl et al. 2011	Impact assessment	Questionnaire	Nehring et al. 2013a; Nehring et al. 2013b; Rabitsch et al. 2013
Full Risk Assessment Scheme for Non-native Species in Great Britain	GB NNRA	Baker et al. 2008	Impact / risk assessment	Questionnaire	Baker et al. 2008; Mumford et al. 2010
Norwegian Generic Ecological Impact Assessments of Alien species	GEIAA	Sandvik et al. 2013	Impact assessment	Excel sheet, Statistical program R	Sandvik et al. 2013
The generic impact scoring system	GISS	Nentwig et al. 2010	Impact assessment	Questionnaire	Kumschick and Nentwig 2010; Nentwig et al. 2016
The generic impact scoring system including IUCN criteria	*GISS IUCN*	Blackburn et al. 2014	Impact assessment	Questionnaire	Blackburn et al. 2014
HARMONIA+	HARMO-NIA+	D'hondt et al. 2015	Impact assessment / screening tool	Online tool	D'hondt et al. 2015
Global threat scoring system	GLOTSS	Molnar et al. 2008	Impact assessment	Questionnaire	Molnar et al. 2008
Risk assessment for exemptions from ballast water management	RABW	David et al. 2013b	Risk assessment	Questionnaire	David et al. 2013b
Species Biofouling Risk Assessment	SBRA	Hewitt et al. 2011	Risk assessment	Questionnaire	Hewitt et al. 2011
Trinational Risk Assessment for Aquatic Alien Invasive Species	TRAAIS	Mendoza et al. 2009	Risk assessment	Questionnaire	Mendoza et al. 2009
Invasive Species Impact and Prevention/Early Action Assessment Tool	WISC	WISC 2009	Risk assessment	Questionnaire	WISC 2009

3.2 AquaNIS information system and *nNIS* index

3.2.1 AquaNIS data type

This part of the study is based on the data accumulated from the information system on Aquatic Non-Indigenous and Cryptogenic Species – AquaNIS, where all geographic information is arranged in a hierarchical order ranging from oceans, ocean sub-regions, LMEs, sub-regions of LMEs to smaller entities, such as ports (Olenin et al. 2014; AquaNIS 2019). All countries are linked to relevant LMEs or LME sub-regions. This provides database search combinations "country + LME" or "country + LME sub-region" for different coasts and for a country that borders different seas, e.g.: "Germany within the LME 23 Baltic Sea". Such data may also be aggregated at different geographical scales and in different combinations, e.g. "LME 22 North Sea + LME 23 Baltic Sea", or "Germany within both the North Sea and Baltic Sea coasts", which would be needed to define the level of primary introduction. The basic data entry in AquaNIS is an introduction event record, documenting a species introduction into a recipient region, defined as a country or a country sub-area with in an LME or LME sub-region. The registration of an introduction event includes the year of the first record when a species was noticed in a recipient region as well as pathways and vectors of introduction according to different levels of certainty. In addition, AquaNIS gathers and disseminates information on species biological traits, environmental tolerance limits, availability of molecular data for identification, habitats, etc. Moreover, the information system is equipped with a structured "search" function that allows for retrieving and organizing data by multiple and complex search criteria (Olenin et al. 2014).

3.2.2 *nNIS* index application

Assessment unit, initial and periodic assessments. *nNIS* is index which shows the number of new NIS in an assessment unit. In this study, the assessment unit is equal to a recipient region as it is in AquaNIS database. In the Baltic Sea, there are 10 recipient regions: eight bordering countries and the two separate regions of the Russian Federation, the Sankt-Petersburg area in the Gulf of Finland (RU_S) and the Kaliningrad area in the south-eastern Baltic (RU_K). The initial assessment is the first inventory of all NIS present in a recipient region. For example, most EU Member States have performed an initial environmental status assessment under the MSFD and reported the cumulative number of NIS in the waters under their jurisdiction recorded by 2010. In this study, all new NIS, arriving to the Baltic Sea during 2000 - 2018 period were gathered, to make overview of changes; in addition, this periodic assessment was divided into two periods: 2000 – 2009 and 2010 – 2018. A periodic assessment is a record of new NIS arrived to a recipient region since the first inventory. The periodicity of the assessment may be defined by the management needs, for example, it will be 6 years for MSFD and in maximum 5 years for granting ballast water management exemptions under BWMC (Olenin et al. 2016).

The level of primary introduction and the secondary spread. A primary introduction is the first arrival of a NIS to a particular assessment unit, while the secondary spread is its further dispersal to other locations. The level of a primary introduction can be assessed at different geographical scales, from a recipient region or an LME or a larger biogeographical area. From the environmental policy point of view, more important are those primary introductions, which are new not only for a coast of a particular country (recipient region), but for an entire LME or, even for a larger biogeographical region, for example for two or more neighboring LMEs or LME sub-regions. The levels of primary introduction should be defined for each case study separately, depending on the availability of data for larger geographical scales. In the Baltic case study, the lowest level of primary introduction (L1) is one of the 10 recipient regions, the next level (L2) is the entire LME (Baltic Sea), and the highest level (L3) is two neighboring LMEs (Baltic Sea and North Sea). Thus, *nNIS* L1 shows how many new NIS were recorded in a particular country, *nNIS* L2 shows how many of them were new for the Baltic Sea, and *nNIS* L3 indicates the number of NIS new for both the Baltic and the North seas.

Data extraction method. AquaNIS offers an opportunity to extract the value of *nNIS* L1 directly, using the built-in "Search" function for the recipient region and year, from which the new arrivals should be calculated. The system can retrieve the number of species (i.e., *nNIS* L1) and the number of introduction events. Data extraction for *nNIS* L2 and L3 values involves several steps, using a combination of "Search" and "Comparison of search results" functions (Table 4).

Table 4. **Standard data extraction**

4 lentelė. **Duomenų gavybos procedūra**

Step	Function	Action	Explanation
1	"Search"	Select NIS registered in an LME or a country with several recipient regions (such as the Baltic Sea) since the year of the initial assessment (e.g. "from 2000"). Include (save) in "Search 1".	Retrieved is the number of NIS, which were involved in introduction events since the initial assessment. A part of them are truly new NIS for this recipient region, others were involved in the secondary spread from other recipient regions.
2	"Search"	Select species registered in the same area as above before the year of the initial assessment (e.g. "before 1999"). Include (save) in Search 2.	Retrieved is the number of NIS, which were known in the area before the initial assessment.

Step	Function	Action	Explanation
3	"Comparison of search results"	Compare Search 1 and Search 2.	Retrieved is the number of truly new NIS, which arrived to the recipient region since the initial assessment.
4	"Further analysis"	Determine new NIS which have appeared in the recipient regions.	The list of the recipient regions shows the geographical "windows" ("hot spots") of primary introductions into a particular LME or a country, and number of NIS involved.
5	"Further analysis"	Determine pathways/ vectors involved in primary introductions. Retrieved is the number of NIS, which were involved in introduction events since the initial assessment. Part of them are truly new NIS for this recipient region, others were involved in the secondary spread from other recipient regions.	This list helps to rank pathways/vectors according to their importance in primary introductions, indicating also the level of certainty.

The calculations of all *nNIS* values presented here are based on data that has accumulated in AquaNIS till April 12, 2019 (AquaNIS 2019). According to the AquaNIS (2019) definition, an introduction event should be ascribed to a pathway/vector with the defined level of certainty (Table 5).

Table 5. **Levels of certainty applied for pathways and vectors in AquaNIS***

5 lentelė. **Patikimumo lygiai, taikomi rūšių patekimo keliams ir vektoriams AquaNIS* sistemoje.**

Level	Criteria
Direct evidence	A species was actually found associated with the specific vector(s) of a pathway at the time of introduction to a particular locality within a recipient region.
Very likely	A species appears for the first time in a locality where a single pathway/ vector(s) is known to operate and where there is no other explanation that can be argued for a NIS presence except by this likely pathway/vector(s).
Possible	An introduction event cannot be convincingly ascribed to a single pathway/ vector, because more than one pathway could be involved and/or different life stages of the same species may be transported by different vectors of the same pathway, the lowest level of certainty
Unknown	No pathway/vector for a transmission can be identified with any level of certainty

* - based on Minchin 2007; Olenin and Minchin 2011.

In order to test if NIS salinity tolerance range is a limiting factor for the spread, NIS were categorized according to information on the number of salinity zones where species are able to reproduce and spread. The number of salinity zones was based on the Venice salinity system (see Annex 6).

Assessments of biopollution level (BPL) index. The BPL index assessment was extracted from AquaNIS 2019 (AquaNIS 2019) (Olenin et al. 2007). The methodology (Olenin et al. 2007) is based on a classification of the abundance and distribution range of alien species and the magnitude of their impacts on native communities, habitats and ecosystem functioning aggregated in a „biopollution level" index (BPL) which ranges from „no impact" (BPL = 0) to „massive impact" (BPL = 4). Additional data about NIS impact on environment stored in the information system was used for the analysis: the reproduction type, development trait, habitat modification abilities, bio-accumulation potential.

3.3 Mean expansion rate as a tool to measure the invasiveness

Invasiveness. Natural processes, typically referred to as range expansions, occur over long timeframes and generally result from the breakdown of biogeographic barriers between adjoining biogeographic provinces. In this study we define "invasiveness" as human-mediated movements of species, known specifically as biological introductions, which occur in ecological timeframes of weeks to years and transcend the geographies of natural species' range expansions.

Spread measure. The method is based on semi-quantitative ecological impact assessment scheme (Sandvik et al. 2013). Expansion is defined as any increase in a species area of occupancy or extent of occurrence, irrespective of the pathways and vectors involved. Expansion is described as not only self-movement of individual organisms and dispersal (through animals, water, wind, or other means) but also as anthropogenic transport and separate introductions (intentional or otherwise) (Sandvik et al. 2013).

The expansion rate is modelled as the mean speed v of actual or assumed invasion front, using all observations of the species. The speed of invasion front is obtained using linear regression under the assumption of sampling error and no process variance. An R – script that carries out the estimation of expansion rate as described here, is available from http://www.evol.no/hanno/12/expans.htm. The mean expansion rate is then modelled as the mean speed v of an actual or assumed invasion front, using all observations of the species. The counted invasion front (mean expansion rate), inferred using all individual observations of the species, irrespective of how the species might have ended up there. Based on the algorithm (see Sandvik et al. 2013) two different values: a) estimates of the expansion rate ($v \pm 95\%$ confidence intervals) and of the standard deviation of the spread distance s, based on the assumption of no observation error (hypothesis that all variation is assumed to be due to process noise); b) estimates (± 95% confidence intervals) based on the assumption of no process noise (i.e., all variation is assumed to be due to observation error) were counted. The ranking of invasion potential subcategory thresholds were derived for Norway country area, according to Sandvik et al. (2013), these thresholds may require specification for applying them to different scale areas.

Geo-referenced data extraction. The georeferenced data was extracted from the scientific publications and specialized databases (AquaNIS, ICES and Google Scholar). All georeferenced data according to their origin were divided into three types: *exact coordinates* - coordinates of a sampling point where the species was found, extracted from the data provider source (ICES, scientific articles); *map digitalization* - coordinates extracted manually from the published map(s) using software such as Google Maps; *expert judgement* - extraction of data by an expert based on verbal description of a finding location (e.g. “a species was found in the northern part of the Curonian Lagoon”).

Data availability for MER calculation. The geo-referenced data of *Rangia cuneata* was used to count the average of the distances that are at least as large as the single largest distance in the previous year. In other words, the bivalve *R. cuneata* first introduction observation in a given year was ignored if any observation date lied behind (i.e. closer to the 1st observation than the largest distance observed in the earlier years); the average of the remaining observations defines the invasion front in the present year. Geo-referenced data is presented in the Annex 8. MER was also used to determine the invasion potential of 10 species which either newly arrived to the Baltic Sea or have changed their distribution since 1987 (AquaNIS 2019). Species selection and sites for data collection were chosen according to data existence, the total number of geo-referenced data was equal to 1302 total points (Annex 3_1).

3.4 Data analysis methods and statistical procedures

The nMDS analysis was used in order to assess the taxonomic similarity of NIS assemblages introduced during the 2000 – 2018 period between the Baltic Sea countries (Fig. 18). Prior to the statistical analyses, the data were standardized. Non-parametric multi-dimensional scaling (nMDS) analysis, based on the Bray-Curtis similarity coefficient was employed to demonstrate the taxonomic similarity of non-indogenous species introduced in to the Baltic sea countries. Statistical comparisons between 2 or more groups were performed by using Spearman rank correlation. The statistical analyses were performed using PRIMER v. 6 and Brodgar softwares. The significance level for all used tests was considered as $p < 0.05$, $p<0.01$.

4

Results

4.1 Deriving evaluation criteria from legislative documents

In order to assess the quality of risk and impact assessment methods the comparison of two legislative documents was performed, and the evaluation framework was developed (Fig. 7). The IMO Guidelines define three approaches of RA: i) environmental matching, ii) biogeographical and iii) species-specific. All of these approaches are reflected in each of the eight articles outlining RA components in the EU Regulation. However, the IMO guidelines do not directly correspond with the two equivalent articles within the EU Regulation (*Art 5(1)(g)* and *Art 5(1)(h))* (Table 3), and only partially refer to the six other articles. Furthermore, the EU Regulation gives a brief description of those components that need to be addressed in RA methodologies. All twenty-nine RA components of the EU Regulation were included in an overall evaluation procedure in this study (Table 3).

The screening revealed the differences and similarities between two documents, which are summarized in Table 7.

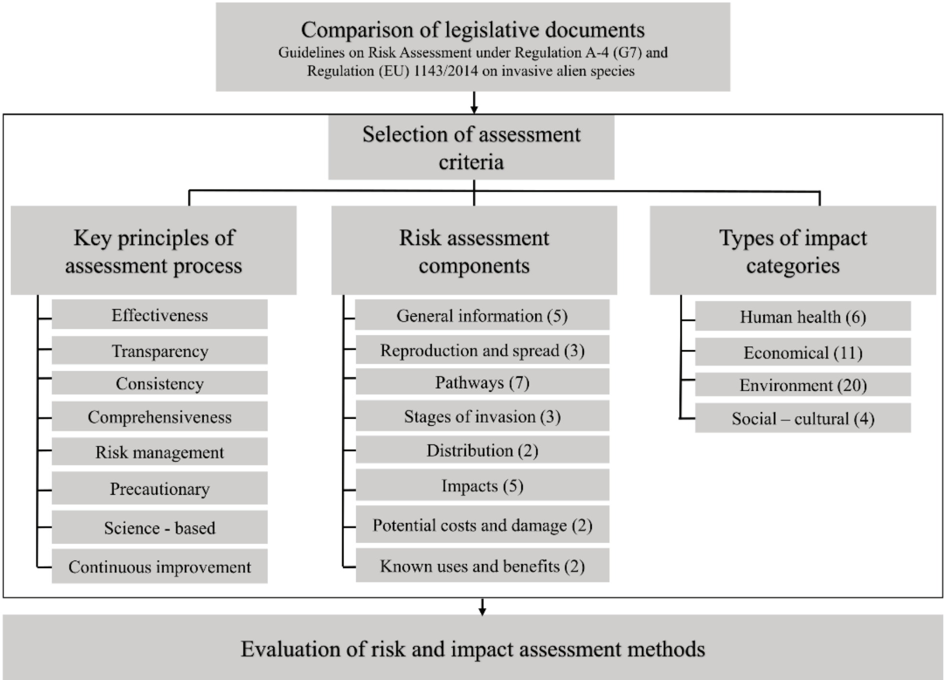


Figure 7. A stepwise process of the evaluation of bioinvasion risk and impact assessment methods: comparison of legislative documents, selection of criteria and evaluation. The number of elements in risk assessment components and categories in types of impact is given in brackets.

7 pav. Pakopinis/laipsniškas biologinių invazijų rizikos ir poveikio vertinimo metodų įvertinimo procesas: teisinių dokumentų palyginimas, kriterijų atranka ir vertinimas. Rizikos vertinimo sudedamųjų dalių ir atskirų kategorijų elementų skaičius poveikio tipuose pateikiamas skliausteliuose.

Table 7. **The analysis of the EU regulation risk assessment frameworks and IMO guidelines. The EU regulation* (*italic*) and IMO guidelines* (plain text): risk assessment frameworks. IC: Incorporation of the criteria; ○: criteria only in IMO Guidelines (specifically, point G7); ●: criteria only in EU regulation (specifically Article 5.1); ◑: criteria in both documents. IA: IMO RA approach type; ■: environmental matching risk assessment; ▲: species biogeographical risk assessment; □: species-specific risk assessment.**

7 lentelė. **TJO gairių ir ES reglamento rizikos vertinimo nuostatų analizė. ES reglamento* (kursyvu) ir TJO gairės* (paprastuoju šriftu) IC: vertinimo kriterijai; ○: TJO gairių kriterijai; ●: ES reglamento kriterijai; ◑: kriterijai minimi abiejuose dokumentuose. IA: TJO rizikos vertinimo tipas; ■: aplinkos sąlygų; ▲: biogeografinis; □: atskirų rūšių vertinimas.**

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
Key principles of the assessment process**	Effectiveness	○	
	Reliable scientific information supported by references to peer-reviewed scientific publications / transparency	◑	
	Consistency	○	
	Comprehensiveness	○	
	Risk management	○	
	Level of uncertainty or confidence, quality control, overall risk / precautionary	◑	
	Scientific robustness, efficiency of knowledge / science based	◑	
	Continuous improvement	○	
Risk assessment components	*Species taxonomic identity, history, natural and potential range (Art 5(1) (a))*		
	1. *The description of the species*	●	
	2. *The scope of the risk assessment*	●	
	3. *Taxonomic identity of the species*	●	
	4. *Invasion history of the species, including information on countries invaded, an indication of the timeline of the first observations, establishment and spread /* information on life history and physiological tolerances, estimate potential to survive or complete its life cycle, individual species characteristics, biogeographical distributions of nonindigenous species, native species with wide biogeographical or habitat distributions, invaders in other biogeographic regions, environmental matching degree of similarity between the locations.	◑	■▲□

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
	5. *Natural and potential range of the species, an indication of the continent or part of a continent, climatic zone and habitat where the species is naturally occurring /* identify species that are present in the donor port but not in the recipient port, current distribution within the biogeographic region and in other biogeographic regions, environmental conditions of the source region should be considered.	◑	■□
	Reproduction, spread patterns, dynamics, an assessment of environmental conditions for reproduction and spread (Art 5(1) (b))		
	1. *Reproduction and spread patterns: species life history and behavioral traits, ability to establish and spread, reproduction or growth strategy, dispersal capacity, longevity, environmental and climatic requirements, specialist or generalist characteristics* / information on life history and physiological limits, estimate its potential to survive or complete its life cycle, the degree of similarity between the locations, the likelihood of survival and the establishment.	◑	■□
	2. *Reproduction patterns and following elements: suitable environmental conditions for the species reproduction exist in the risk assessment area, e.g. number of gametes, seeds, eggs or propagules, number of reproductive cycles per year* / information on life history and physiological limits, estimate its potential to survive, complete its life cycle, degree of similarity between the locations provides an indication of the likelihood of survival and establishment, compare environmental conditions to determine the likelihood ability to survive.	◑	■□
	3. *Spread patterns and dynamics and following elements* / information on life history and physiological tolerances to define a species physiological limits, estimate its potential to survive, complete its life cycle, degree of similarity between the locations provides an indication of the likelihood of survival and establishment, analysis of environmental conditions be followed that can tolerate extreme environmental differences.	◑	■□

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
	Potential pathways of introduction, spread, intentional and unintentional, the associated commodities(Art 5(1) (c))		
	1. *Relevant pathways for introduction and spread. The classification of pathways by the Convention on Biological Diversity* / identify the species that have the ability to invade and become harmful and relationship with ballast water as a vector, records of native or non-indigenous species that could be transferred through ballast water.	◑	▲□
	2. *Intentional pathways of introduction and following elements* / identify the species that have the ability to invade and become harmful and relationship with ballast water as a vector, records of native or non-indigenous species that could be transferred through ballast water.	◑	▲□
	3. *Unintentional pathways of introduction and following elements* / identify the species that have the ability to invade and become harmful and relationship with ballast water as a vector, records of native or non-indigenous species that could be transferred through ballast water.	◑	▲□
	4. *Commodities with which the introduction of the species is generally associated, commodities with an indication of associated risks (e.g. the volume of trade flow; the likelihood of the commodity being contaminated or acting as a vector)* / identify the species that have the ability to invade and become harmful and relationship with ballast water as a vector, seasonal variations in surface and bottom salinities, determine the full range of environmental conditions available for a potential invader.	◑	▲□
	5. *Intentional pathways of spread and following elements: commodities with an indication of associated risks (e.g. the volume of trade flow, the likelihood of the commodity being contaminated or acting as a vector)* / records of species that could be transferred through ballast water, the number, nature of biogeographic regions invaded, life history, physiological tolerances, physiological limits, estimate its potential to survive, complete life cycle in the recipient environment, species characteristics with the environmental conditions, determine the likelihood of transfer and survival.	◑	▲□

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
	6. *Unintentional pathways of spread and following elements /* records of species that could be transferred through ballast water in the donor biogeographic region, invaded other biogeographic regions, number and nature of biogeographic regions invaded, life history and physiological limits, estimate its potential to survive, complete its life cycle in the recipient environment.	◑	▲□
	7. *Commodities with which the spread of the species is generally associated, commodities with associated risks (e.g. the volume of trade; the likelihood of a commodity being contaminated or acting as vector) /* records of species that could be transferred through ballast water, life history and physiological limits, estimate its potential to survive, complete its life cycle in the recipient environment, individual species characteristics with the environmental conditions, determine the likelihood of transfer and survival.	◑	▲□
	Assessment of the risk of introduction, establishment, spread in biogeographical regions in current and climate change conditions (Art 5(1) (d))		
	1. *Assessment risks of a species introduction into, establishment, spread within relevant biogeographical regions, explanation how foreseeable climate change conditions will influence risks /* biogeographical distributions; identify potential target species in the donor regions with wide biogeographical or habitat distributions, known invaders in other biogeographic regions/ environmental conditions compared, similarity in key environmental conditions, environmental conditions for environmental matching include temperature, nutrients, oxygen or other.	◑	■▲□
	2. *Assessment of likely introduction, establishment and spread within a medium timeframe scenario (e.g. 30-50 years).*	◑	■▲□

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
	3. *Description of risks can be in terms of 'likelihood' or 'rate'* / degree of similarity between the locations indicates the likelihood of survival and the establishment, species characteristics with the environmental conditions to determine the likelihood of transfer and survival, likelihood of target species survival, probability of viable stages entering the vessel's ballast water tanks, probability of survival during the voyage, probability of viable stages entering the recipient port through ballast water discharge on arrival.	◑	□
	Current distribution, projection of its likely future distribution (Art 5(1) (e))		
	1. *Current distribution in the risk assessment area or in neighbouring countries* / biogeographical distributions of species that presently exist in biogeographic regions; records of invasion in biogeographic regions and ports/ biogeographic region of donor and recipient port(s); the presence of target species in the recipient port(s), port region, and biogeographic region.	◑	▲□
	2. *Likely future distribution in the risk assessment area or in neighbouring countries* / identify potential target species with wide biogeographical or known invaders in other biogeographic regions, the presence of target species in the recipient port(s), port region, and biogeographic region; life history information on the target species and physiological tolerances, in particular salinity and temperature, of each life stage; habitat type required by the target species and availability of habitat type in the recipient port, the likelihood of target species surviving.	◑	▲□
	Adverse impact on biodiversity, ecosystem services, native species, protected sites, endangered habitats, human health, safety, economy, potential future impact (Art 5(1) (f))		
	1. *Known impact or potential future impact on biodiversity and related ecosystem services. The potential future impact in the risk assessment area* / records of native that have the potential to affect or result in substantial ecological impacts / species of concern that may impair or damage the environment need to be identified and selected (e.g. target species). Target species should be selected for a specific port, State, or geographical region, and should be identified and agreed.	◑	▲□

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
	2. *Known impact and the assessment of the potential future impact. The magnitude of the impact scored or otherwise classified. The impact scoring or classification system include a reference to the underlying publication /* species biogeographical risk assessment compares the biogeographical distributions of nonindigenous, cryptogenic, and harmful native species that presently exist in the donor and recipient ports and biogeographic regions.	◑	▲
	3. *Known impact and the assessment of the potential future impact on biodiversity /* records of native species have the potential to affect, result in ecological impacts / target species selected on criteria that identify the ability to invade and become harmful; demonstrated impacts on environment, economy, human health, property, resources; strength and type of ecological interactions, e.g. ecological engineers; current distribution within biogeographic region and in other biogeographic regions; relationship with ballast water as a vector.	◑	▲□
	4. *Known impact and the assessment of the potential future impact on related ecosystem services.*		
	5. *Known impact and the assessment of potential future impact on human health, safety and the economy /* records of native species have the potential to affect human health, result in ecological, economic impacts / species of concern that may impair or damage the environment, human health, property or resources, target species should be selected for a specific port, State, or geographical region.	◑	▲□
	Potential costs of damage (Art 5(1) (g))		
	1. *The assessment, in monetary or other terms, of the potential costs of damage on biodiversity, ecosystem services.*	●	
	2. *The assessment of the potential costs of damage on human health, safety, and the economy.*	●	
	Known uses for the species, social, economic benefits (Art 5(1) (h))		
	1. *Description and list of known uses of species.*	●	
	2. *Social and economic benefits from the known uses for the species, environmental, social and economic relevance and an indication of associated beneficiaries.*	●	

Assessment criteria	Comparison of criteria by IMO and EU regulation risk assessment frameworks	IC	IA
Types of impact categories	*Human health* / Human health	◑	□
	Economy / Economy	◑	□
	Environmental / Environment	◑	□
	Social –cultural / Property or resources	◑	□

* IMO 2007; EU 2018; **precise definitions of the key principles are given in Table 2

4.2 Comparison of risk and impact assessment methods

4.2.1 Key principles of assessment process

The second part of the evaluation and analysis of the risk and impact assessment methods were tested for quality of assessment process. The summary of the evaluation of compliance with the key principles is presented in Table 8 and detailed evaluation results are given in Annex 2.

Effectiveness: all methods complied with this principle and provided definitions of each parameter used and included basic information as to how the assessment process could be undertaken.

Transparency: it was adequately addressed in three methods (BINPAS, CMIST, HARMONIA+). These tools are freely available as online information systems (Annex 2). Other methods, while compliant with this principle, were less developed in this respect. Some methods (e.g. GB NNRA, GEIAA) provided either fully or in part through an available online service with an option to enter results to an online database. A further group of methods (e.g. AS-ISK, CIMPAL, GABLIS) was based on case studies in the scientific literature, but these do not store results in any available database.

Consistency: according to the published data there were only four methods (AS-ISK, CMIST, GISS, HARMONIA+) we were able to examine for consistency, i.e., for repeatability of the test outcomes (Annex 2). Such a consistency was evaluated based on either expert judgment (e.g. D'hondt et al. 2015) or statistical scrutiny (Drolet et al. 2016). All remaining methods were considered to be non-compliant with the "consistency" principle as no relevant available published results were found.

Comprehensiveness: three methods complied with this principle (e.g. GB NNRA, SBRA, RABW) that considered all four bioinvasion impacts, i.e. human health (HH), economic (EC), environmental (EN) and social - cultural (SC). Three other methods (AS-ISK, GABLIS and HARMONIA+) considered EN, EC, SC, and further three methods (TRAAIS, WISC and GISS) took into account only two impacts EN, EC, while all other methods considered just environmental impacts.

***Table 8.* Comparison of methods used for risk assessment is based on key principles. “1” means that the method is completely covered, according to key principle and their criteria; “0” the method is not designed to cover any of the key principles and their criteria.**

***8 lentelė.* Rizikos vertinimo metodų palyginimas pagal pagrindinius principus. „1“ - vertinama, kai metodas yra pilnai atitinka pagrindinį principą ir jo kriterijus; „0“ - neatitnka pagrindinių principų ir jų kriterijaus.**

Key principles	Bioinvasion risk and impact assessment methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	GLOTSS	RABW	SBRA	TRAAIS	WISC
Effectiveness	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Transparency	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Consistency	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0
Comprehensiveness	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
Risk management	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1
Precautionary	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
Science based	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Continuous improvement	1	1	1	1	0	1	0	1	0	1	0	1	1	0	1
Total coverage (%)	***88***	***75***	***63***	***88***	***50***	***75***	***50***	***88***	***63***	***88***	***63***	***75***	***88***	***63***	***75***

Risk management: the majority of the methods (12 out of 15) fully addressed the “risk management” key principle by providing rankings of impact magnitude that could be used for making risk management decisions.

Precautionary: fourteen out of fifteen methods fully addressed this principle and provided confidence levels for a final score and described how to define uncertainty. Two methods (GB NNRA and GEIAA) incorporated levels of confidence for all risk assessment steps, but did not deal with levels of uncertainty. One method (GABLIS) did not provide any level of uncertainty or a confidence level.

Science-based: all methods either complied fully, or in part, with justifying statements based on either experimental, field studies, or literature reviews.

Continuous improvement: ten of the methods had been updated as in the case of AS-ISK (Copp et al. 2016), which evolved from the first version of FISK (Copp et al. 2009), while the original design was based on the Weed Risk Assessment methodology (Pheloung et al. 1999). Two methods (BINPAS and CMIST) have been computerized following a theoretical background (Olenin et al. 2007 and IASWG 2009) in order to provide an opportunity for online application (Narščius et al. 2012; Drolet et al. 2016).

4.2.2 Risk assessment components

Based on the analysis it was found that all methods incorporated at least some general information about non-indigenous species under consideration (Table 9; Annex 3), i.e. taxonomic identity, scope of a RA, etc. (EU, 2018). The RA components concerning reproduction and spread, pathways, stages of invasion process, distribution and impacts were incorporated within most methods (Table 9). The least covered components were the estimated consequences of economic damage and any known uses and benefits. This involved four and two methods, respectively.

Table 9. **Incorporation of the risk assessment components and their elements into the selected methods (%). The total number of elements in each risk assessment components indicated in brackets.**

9 lentelė. **Rizikos vertinimo komponentų ir jų elementų įtraukimas į pasirinktus metodus (%). Skliausteliuose nurodytas bendras rizikos vertinimo elementų skaičius.**

RA components*	Relative proportion of RA elements (%) in the methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	GLOTSS	RABW	SBRA	TRAAIS	WISC
General information (5)	**100**	**100**	80	60	**100**	60	**100**	**100**	**100**	**100**	80	**100**	80	**100**	80
Reproduction and spread (3)	**100**	33	67	**100**	**100**	**100**	**100**	0	0	**100**	67	**100**	**100**	67	67
Pathways (7)	71	0	86	29	71	**100**	14	0	57	**100**	57	86	**100**	**100**	**100**
Stages of invasion process (3)	67	33	67	67	67	**100**	67	33	0	**100**	67	67	67	67	67
Distribution (2)	50	50	50	**100**	**100**	**100**	50	50	50	50	**100**	**100**	**100**	0	50
Impacts (5)	80	60	**100**	60	80	**100**	60	80	40	80	60	60	80	80	80
Potential costs of damage (2)	0	0	0	0	0	50	50	0	0	0	0	0	**100**	0	**100**
Known uses and benefits (2)	50	0	0	0	50	0	0	0	0	0	0	0	**100**	0	0
Coverage (%)	***72***	***38***	***69***	***52***	***76***	***83***	***55***	***38***	***41***	***79***	***59***	***72***	***90***	***72***	***76***

*the additional information of RA components, elements and details of the analysis are in Annex 3, for the methods see Table 3.

The incorporation of a RA component into a method was considered as being complete, should all of the elements be covered. For example, all three elements for reproduction and spread were incorporated within eight methods (Annex 3). Only one method (SBRA) incorporated in full or in part all the components, while four methods (GABLIS, GB NNRA, HARMONIA+, WISC) incorporated more than 75% of the RA components.

4.2.3 Types of impact categories

The impacts on human health were considered in 57% of the methods, however, this was mostly as a "general impact on human health", without further clarification. While three methods (GB NNRA, GISS, HARMONIA+) included more detailed information on human health, accordingly: parasites, pathogens, toxic compounds, poisoning and venomous organisms. These results are summarized in Table 10, Fig. 8 and additional information in Annex 4.

No method included all environmental impact categories. However, all had at least one environmental impact category: parasites and pathogens affecting native species, parasite vector, predation, competition, hybridization, habitat change, or population loss caused by an invasive species, etc. A single method (GISS) incorporated 90% of all of the environmental categories, followed by TRAAIS (80%) and SBRA (75%).

Sixty per-cent of the methods included an economic impact category with either the general management costs (60%) or impacts on aquaculture (47%), fisheries (40%) or in relation to irrigation and abstraction (40%). The methods GABLIS, GISS, and SBRA covered more than a half of these economic categories: 55, 64 and 64%, respectively.

Social-cultural impacts were taken into account by 53% of methods, the most frequent category being consequences for recreation and tourism (53%). SBRA took into account seventy-five per-cent of the social-cultural impact categories, the highest coverage of any RA method.

Table 10. **Summary of impact types and categories and their incorporation into the selected methods. Total number of categories in each type of impact is indicated in brackets.**

10 lentelė. **Poveikio tipų ir jų kategorijų suvestinė ir jų įtraukimas į metodus. Skliaustuose nurodytas bendras kategorijų skaičius kiekvienoje poveikio kategorijoje.**

Types of impact	Relative proportion of types of impacts categories (%) in the methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	GLOTSS	RABW	SBRA	TRAAIS	WISC
Human health (6)	33	0	17	0	50	50	0	**100**	0	50	0	17	67	33	50
Economy (11)	46	0	9	0	55	36	0	64	0	36	36	9	64	27	46
Environment (20)	60	65	50	35	60	50	45	90	60	60	45	20	75	80	35
Social – cultural (4)	50	0	25	25	0	25	0	50	0	0	25	0	75	50	50
Coverage (%)	***51***	***32***	***32***	***20***	***51***	***44***	***22***	***80***	***29***	***46***	***34***	***15***	***71***	***56***	***41***

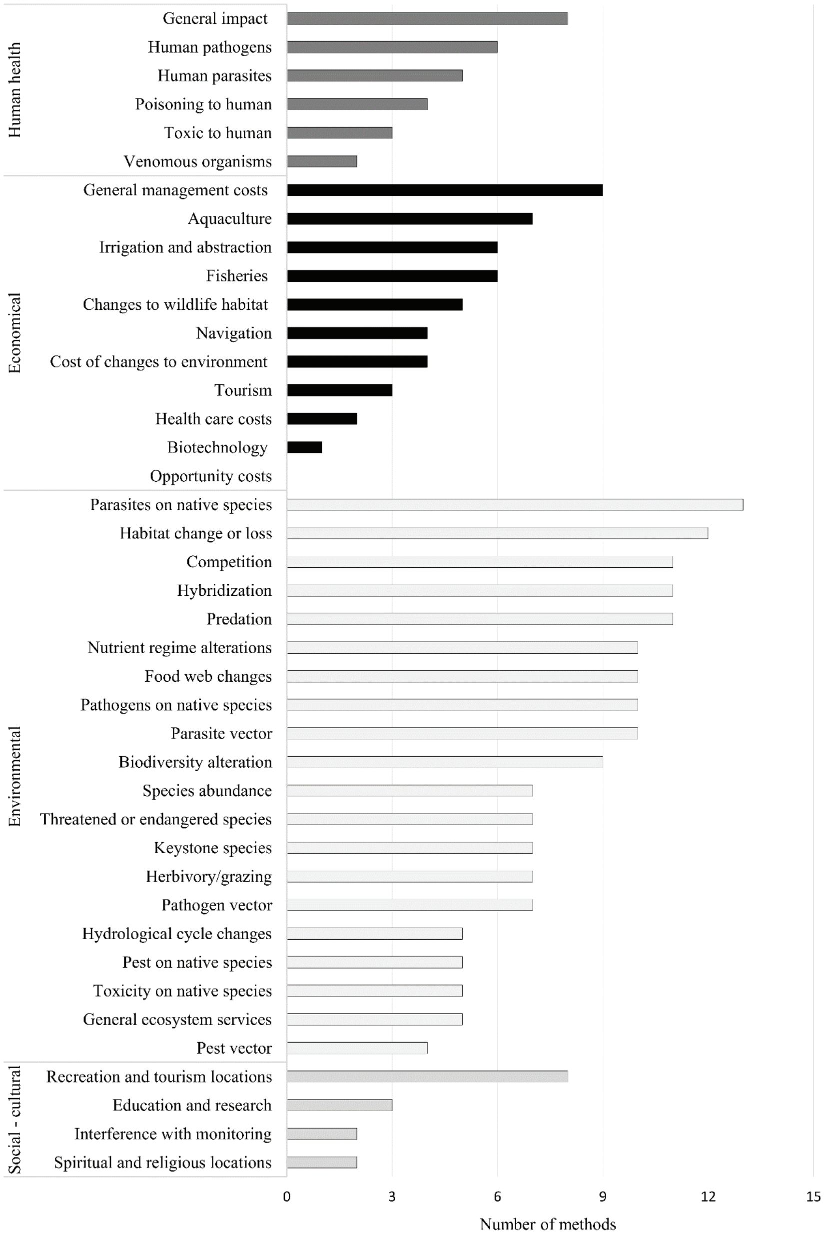


Figure 8. Comparison of categories with impact types in the RA methods. The scale indicates the number of methods with corresponding impact types.

8 pav. Kategorijų ir poveikio tipų taikomų rizikos vertinimo metoduose palyginimas. Skalė žymi metodų skaičių.

4.2.4 Overall evaluation of the methods

The general assessment of the methods by the key principles, RA components and categories of impacts is presented in Fig. 9, while the assessment of the methods according to the criteria appears in Fig. 10. The method that met most of the composed criteria was SBRA (Species Biofouling Risk Assessment). This complied with most of the key principles and RA components, and covered the broadest spectrum of the impact categories and was followed by HARMONIA+ and AS-ISK. However, none of the methods complied with all criteria.

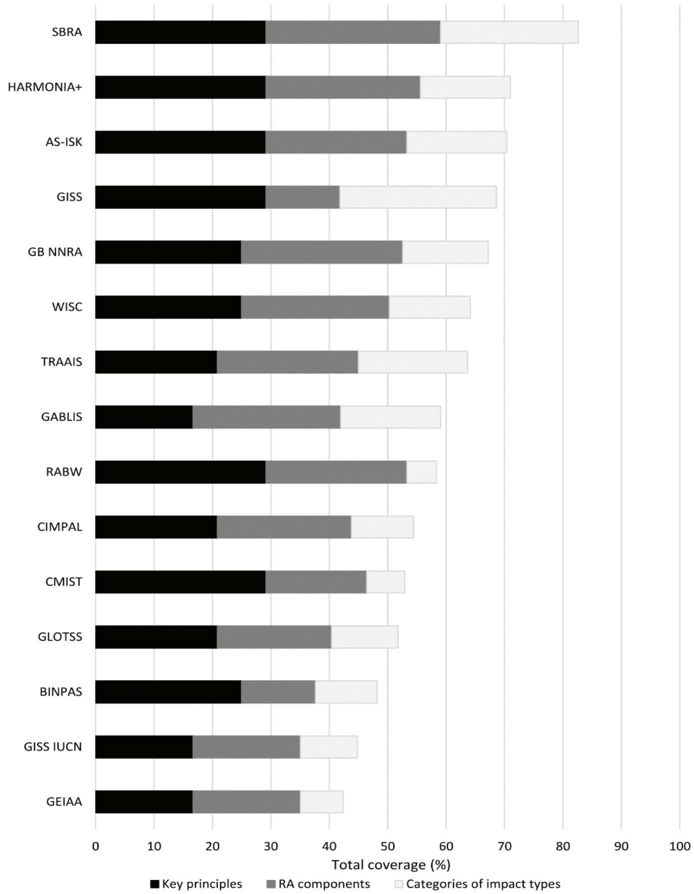


Figure 9. Overall compliance of the methods based on key principles, components and categories of impact types. Each comparison element: “key principles”, “risk assessment component”, “types of impact categories” used in risk assessment method expressed as a cumulative coverage (%).

9 pav. Bendras metodų, kurie remiasi principais, komponentais ir poveikio tipų kategorijomis, atitikimas. Kiekvienas elementas: „pagrindiniai principai“, „rizikos vertinimo komponentas“, „poveikio kategorijų tipai“, taikomi metoduose, išreikšti procentais (%).

A further method that generally complied well with key principles and RA components was RABW, a method developed for the BWMC. However, it has fewer impact categories, although those are associated with aquatic environment. In contrast, GISS incorporates the highest number of impact categories, but has comparatively low compliance with RA components.

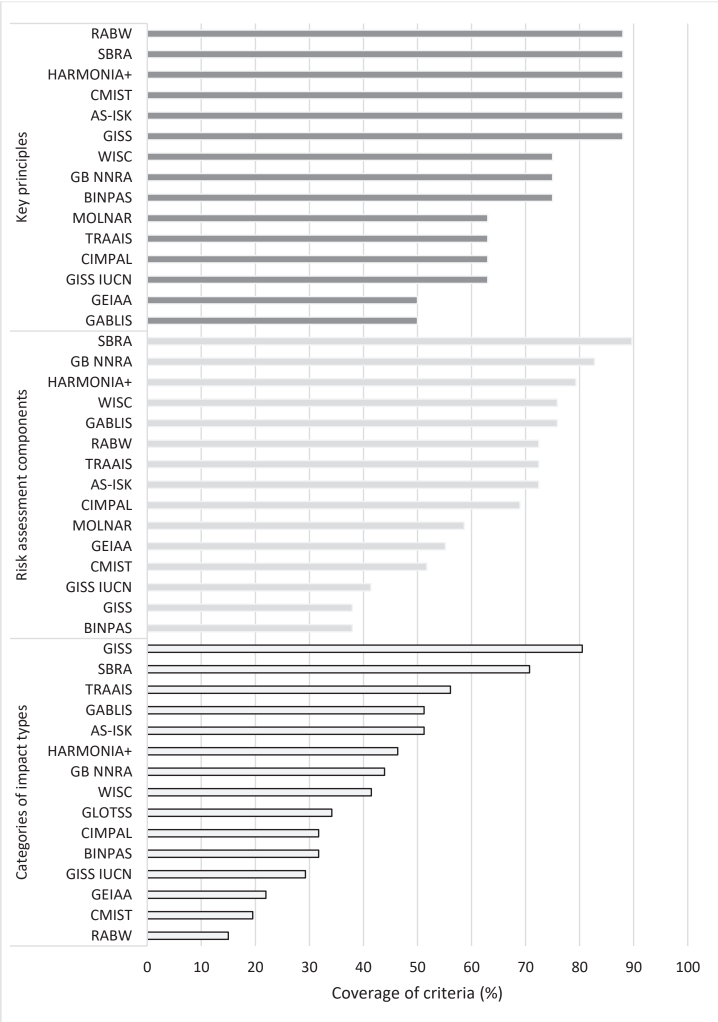


Figure 10. The coverage (%) of risk assessment methods. The scale indicates the percentage of total coverage of each methods correspondence to key principles and risk assessment components, and the list of impact types.

10 pav. Rizikos vertinimo metodų įvertinimo procentinis pasiskirstymas (%). Skalė rodo procentinį pasiskirstymą, kurį sudaro kiekvieno metodo atitikimą pagrindinius principus, komponentus, ir poveikio kategorijų tipus.

According to the analysis, the methods based on three aspects have different correspondence to each. This weakness of the methods should be followed during the update of these methods. The highest correspondence with the key principles was detected for RABW, SBRA, HARMONIA+, CMIST, AS-ISK and GISS, for the risk assessment components − SBRA, and for the categories of impact types − GISS.

4.3 The analysis of the new NIS arrivals in the Baltic Sea since 2000

4.3.1 Taxonomic composition, biological traits and other properties of the new arrivals

In total, there were records for 149 introduction events involving 75 NIS for two periods I (2000-2009) (44) and II (2010-2018) (31) in the countries of the Baltic Sea region (Annex 5).

Taxonomic composition. The comparison of two periods showed that there are differences considering distribution by the taxonomic composition. Most of the NIS recorded in the Baltic Sea countries belong to arthropods (43%); however, the decrease (10%) of this group species was detected in the period from 2010. The second group which dominates in the Baltic Sea is Annelida (15%), Chordata (10%), Mollusca (10%) and Ochrophyta (5%). Most NIS decreased in numbers in the last decade, except the introductions of species which belong to mollusks and cnidarian (Fig. 11).

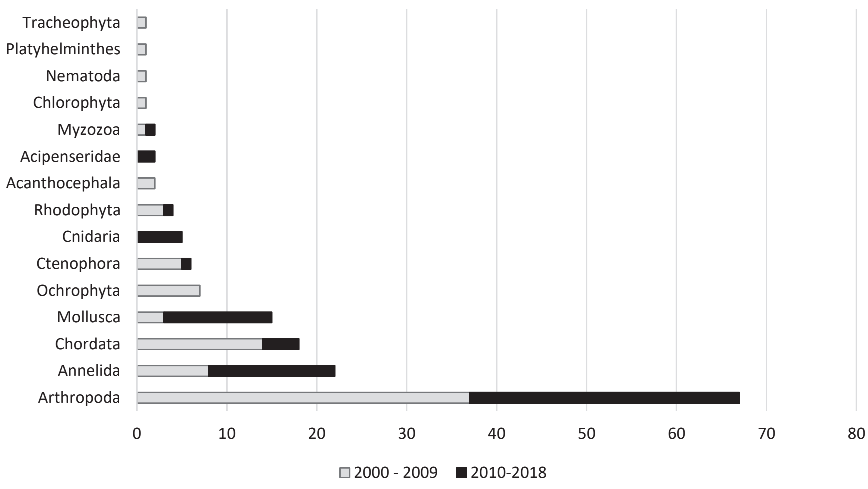


Figure 11. Distribution of non-indigenous species according to phylum level in the Baltic Sea during 2000 – 2018

11 pav. Svetimkraščių rūšių pasiskirstymas pagal tipą Baltijos jūroje 2000 – 2018 periodu

In the period from 2000 there were 7 NIS from ochrophytes, while from 2010 it was not detected in the Baltic Sea. The increase of NIS which belong to Cnidaria phylum was recorded, five new Cnidarian species where detected from 2010. For the period 2000 – 2009 the lowest number of NIS was tracheophytes, platyhelminthes, nematodes, chlorophytes, these species were not detected from 2010.

Biological traits. According to the hypothesis, that NIS species which have a pelagic stage has more potential to spread through ballast water, the study results showed that out of 75 NIS (only primary introductions) which spread into the Baltic Sea region, 63% (47 from 75 NIS) had a pelagic larval stage, 37% (28) did not have pelagic dispersal phase (larvae, eggs, etc.).

However, for some species there are direct proofs of being able to spread with vessels and associated vectors such as ballast waters or biofouling. Out of 47 species which has a pelagic stage 11 NIS where documented that was found in ballast waters and 5 NIS documented as spreading through biofouling.

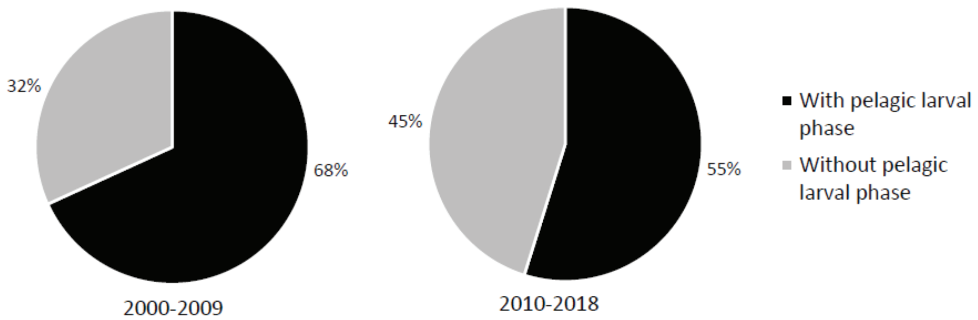


Figure 12. Distribution of non-indigenous species by species with or without pelagic larval stage

12 pav. Svetimkraščių rūšių pasiskirstymas pagal rūšis su pelagine stadija ir be jos

The comparison of NIS with and without pelagic larval development during two periods showed the differences; the decrease of NIS number from 30 to 17 with pelagic larval was detected, while the number of NIS without pelagic stage was the same in both periods (14) (Fig. 12).

For the first period species with pelagic larval stage and without it where 68% and 32%, respectively, while from 2010 a decrease of NIS number with pelagic stage were detected accordingly. Sixteen NIS were spreading during whole period (2000-2018), and most of them (13 out of 16) had a pelagic larval stage (*Marencelleria viridis, Evadne anonyx, Hemimysis anomala, Homarus americanus, Palaemon macrodactylus, Palaemon longirostris, Palaemon elegans, Rhithropanopeus harrisii, Acipenser* *gueldenstaedtii, Neogobius melanostomus, Dreissena bugensis, Mytilopsis leucophaeata, Prorocentrum cordatum*), while three NIS (*Potamothrix moldaviensis*, Gammarus tigrinus, Dikerogammarus villosus*) had no pelagic stage.

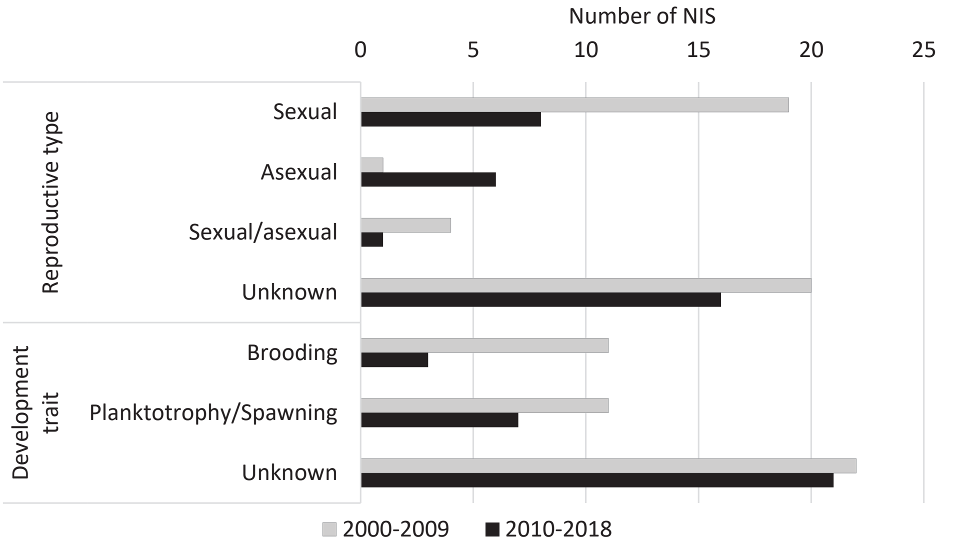


Figure 13. Distribution of non-indigenous species by reproduction type and development trait

13 pav. Svetimkraščių rūšių pasiskirstymas pagal rūšis su pelaginėmis stadijomis arba be jų

According to the biological profile of NIS which had introduction period of 2000 – 2009 the dominating NIS was species with sexual reproduction type, while a high amount of NIS with unknown reproduction type is present for the whole period (Fig. 13). According to the development trait data, two types of reproduction − brooding and planktotrophy/spawning − were dominating, while considering the whole period mostly dominating NIS are developing through spawning (2000 – 2018).

Native origin. According to the analysis of NIS (only primary introductions) on their native origin, the results showed that in the last 18 years NIS from Ponto – Caspian region where dominating (Fig. 14). 33% (25 out of 75) of NIS had either the Black or Caspian Sea as their native region. The second dominating origin was the Northwest (NW) Atlantic (24%), Northwest (NW) Pacific (19%), while Northeast (NE) Atlantic origin constituted only 6% of the NIS origin. For some species, the origin was unknown (11%) and in the case the native region was different (different from Ponto-Caspian, NW Atlantic, NW Pacific) they were assigned as “Others” (5%). Some changes in the origin of the NIS was observed between the two periods. From the year 2010 the decrease of NIS from Ponto – Caspian region (from 39% to 26%), NW Atlantic (from 25%

to 23%) and NE Atlantic (from 9% to 6%) regions were detected. Although the number of the NIS with the origin from other regions such as the NS Atlantic (from 2% to 10%) and NW Pacific (from 18% to 19%) is increasing. A significant increase in NIS which native region is unknown has been detected (from 7% to 16%).

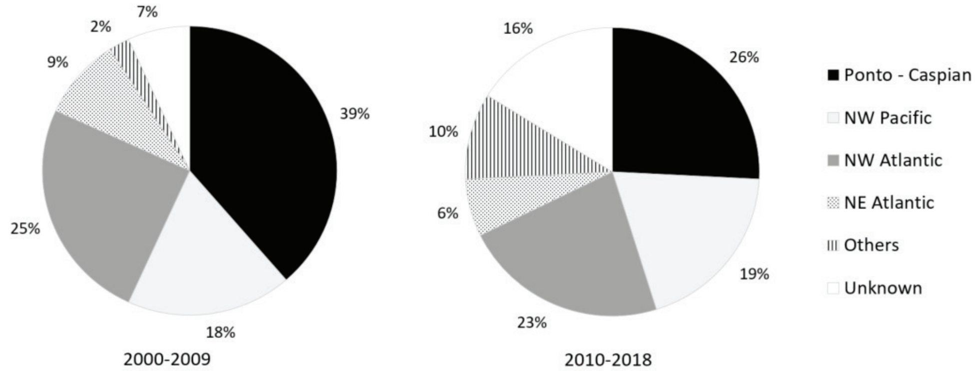


Figure 14. Distribution of non-indigenous species in by native origin

14 pav. Svetimkraščių rūšių pasiskirstymas pagal kilmės regioną Baltijos jūroje 2000 – 2018 m. laikotarpiu

The potential impact on the environment. Using available data on BPL (biopollution level index) the levels of NIS in different parts of the Baltic Sea had been extracted and the highest assessed values for 75 NIS were used for the analysis. The assessment for different countries/regions revealed that the documented ecological impact is only known for 27 out of 75 NIS registered in the Baltic Sea during 2000 – 2018 (Fig.15).

The potential impacts on the environment for most of NIS are not assessed (64%), the reason of this could be the lack of information and a low number of experts on the specific NIS traits and impacts. For six NIS weak biopollution level (BPL=1) was defined in one or more parts of the Baltic Sea, for 13 NIS impact was moderate (BPL=2), for 6 NIS strong (BPL=3), and only for 2 NIS impact was scored as massive (BPL=4). A further example with two NIS mollusk (*Dreissena polymorpha*) and myzozoa (*Prorocentrum cordatum*) shows that the magnitude of the impact can be diverse in different parts of the assessed locations; the variability of impact was from weak (BPL=1) to massive (BPL=4). Thus, according to the results, the overall biopollution level has decreased in the last period (2010-2018), a number of NIS with possible impact was lower. However, the number of species without the assessed impact increased, for the period 2000 – 2009 (48%) and 2010 – 2018 (68%) of NIS which impact on the environment was not assessed.

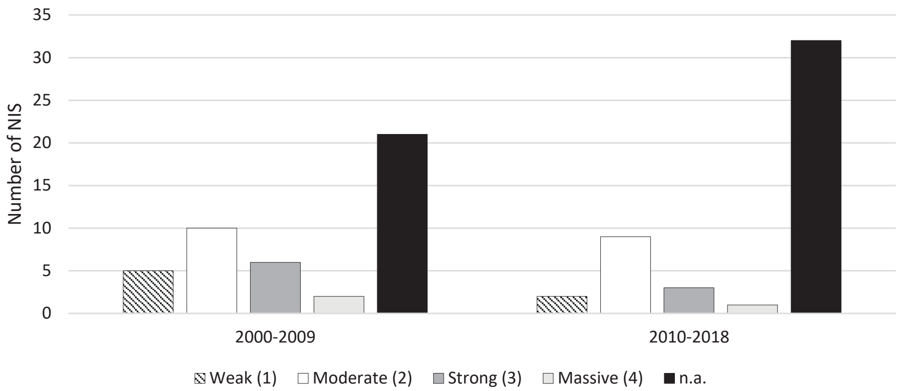


Figure 15. Number of non-indigenous species causing weak (BPL-1), moderate (BPL-2) and strong (BPL-3) biopollution impact. n.a. –impact not assessed

15 pav. Svetimkraščių rūšių skaičius ir poveikio kategorijų pasiskirstymas Baltijos jūroje 2000 – 2018 m. laikotarpiu. n.a. – poveikis aplinkai nevertintas

Other potential impacts such as habitat modification, toxicity and bioaccumulation potential are shown below (Fig. 16).

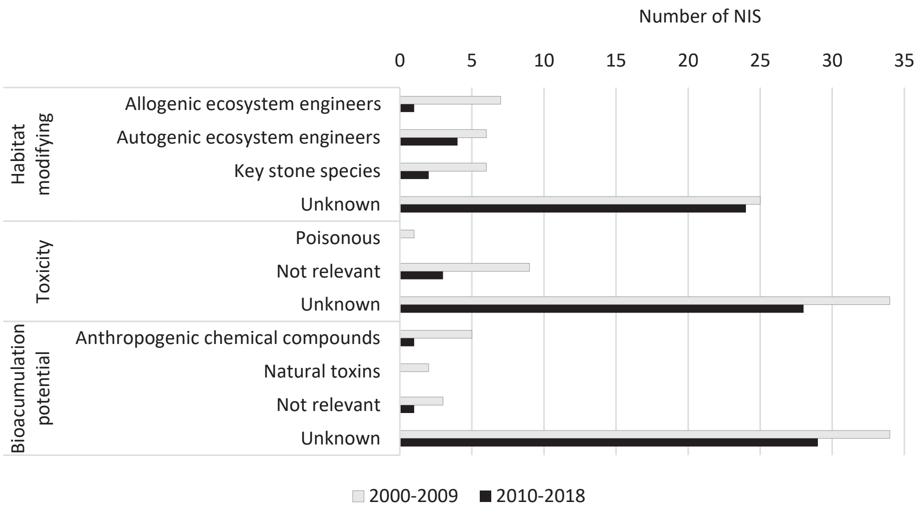


Figure 16. Number of non-indigenous species with possible impact on habitat, toxicity and bioacumulation potential.

16 pav. Svetimkraščių rūšių galimas poveikis buveinėms, toksinis poveikis ir bioakumuliacinis potencialas.

Considering NIS abilities to change the habitat or impact it through poisoning and bioaccumulation of anthropogenic chemicals the information for most NIS is unknown. Based on the available data NIS in a new environment has the potential to make changes to the habitat through the ability to act as allogenic and autogenic ecosystem engineers or having keystone species patterns. Some introduced NIS have abilities to bioacumulate anthropogenic compounds (*R. cuneata*) or natural toxins (*D. polymorpha*) and only one NIS is able to have a poisonous effect (*P. cordatum*).

4.3.2 The ***n***NIS index at different geographical scales

In 7 out of 10 countries/country regions the number of introduction events decreased in the last nine years, while the double increase was detected in Germany (24), a lower number in Poland (13) and in Latvia (7) (Fig. 13). Germany had the highest (34) and Lithuania the lowest (7) number of introduction events during the two assessment periods together (2000 – 2018). Comparing the average number of primary introductions during the periods (2000 – 2009 and 2010 – 2018) there were no significant increase or decrease (8 versus 7), i.e. approximately one introduction event per year was registered in the Baltic Sea region (Fig. 17).

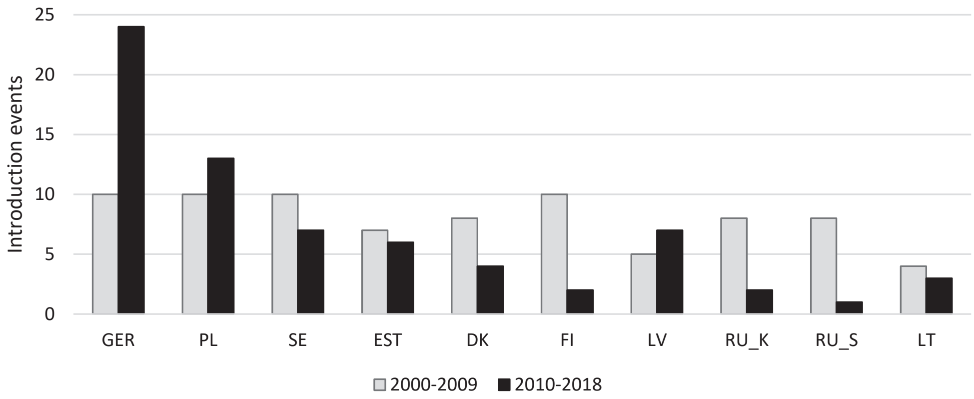


Figure 17. Number of introduction events in the Baltic Sea during the period 2000 – 2018.

17 pav. Introdukcijos įvykių Baltijos jūroje 2000 – 2018 m. laikotarpiu skaičius.

The application results of the proposed index *nNIS* have shown the countries and regions with the highest potential of primary introductions, which were recorded in two periods 2000 – 2009 and 2010 – 2018. The difference between *nNIS* L1 and L2 for a recipient region indicates the number of species, which this particular region received during the assessment period due to the secondary spread from other parts of the Sea. For example, the assessment using *nNIS* revealed that for 2010 – 2018 period 24 NIS were recorded for Germany, i.e. *nNIS* L1_Germany = 24 (Table 11; Annex 5; Fig. 15). It should be noted that the number of the introductions at the level of the larger biogeographical region (Baltic Sea + North Sea, *nNIS* L3) has declined from 9 during 2000-2009 to 6 species during 2010-2018, while the number of species new for the Baltic Sea region (*nNIS* L2) has increased from 20 to 25 (Table 11). This implies that while the number of primary introductions to the Baltic and the North Sea larger region is slightly declining the interregional exchange of previously introduced species, i.e. secondary introductions, has increased.

Table 11. **Summary of *nNIS* index assessment in the Baltic Sea region for the period 2000 – 2018.**

11 lentelė. nNIS **indekso vertinimų suvestinė Baltijos jūros regionui 2000 – 2018 periodu.**

Country/country region	*nNIS* scale					
	L3	*L2*	*L1*	*L3*	*L2*	*L1*
	2000-2009			*2010-2018*		
Denmark	**0**	4	8	**1**	2	4
Sweden	**1**	4	10	**0**	1	7
Finland	**0**	0	10	**0**	0	2
Russia/St. Petersburg	**2**	3	8	**0**	0	1
Germany	**1**	1	9	**2**	14	24
Estonia	**3**	3	7	**2**	3	6
Latvia	**1**	1	5	**0**	0	7
Lithuania	**0**	0	4	**0**	0	3
Russia/Kaliningrad dist.	**2**	2	8	**0**	1	2
Poland	**1**	2	10	**1**	4	13

Fourteen out of twenty-four introductions were primary introductions to the Baltic Sea (*nNIS* L2_Germany = 14), and two of these (mollusk *Haminoea solitaria* and arthropoda *Eurytemora carolleeae*) were new at the level of the larger biogeographical region, comprising both the Baltic Sea and the North Sea LME (*nNIS* L3_Germany = 2).

In Poland, thirteen new species were recorded, four of them appeared newly in the Baltic since 2010, and one NIS *Potamothrix hammoniensis* was new for the Baltic and North seas. The latter is new at the scale L3, i.e. this species entered the Baltic Sea and North Sea via the Polish coast. In Lithuania three new NIS appeared, however none of them was new at the LME level (*nNIS* L2_Lithuania = 0 or *nNIS* L3_Lithuania = 0).

Another example of *nNIS* L3 was the brackish water clam *Rangia cuneata*, the first occurrence in the Baltic was recorded in 2010 in the Russian part of the south-eastern Baltic (RU_K) and during the assessment period it has spread to three other recipient regions:

Poland, Lithuania and Estonia (Annex 5). The sedentary polychaete *Hypania invalida* was found simultaneously in the water body shared between Germany and Poland (Szczecin Lagoon); therefore, the primary introduction is ascribed for two countries.

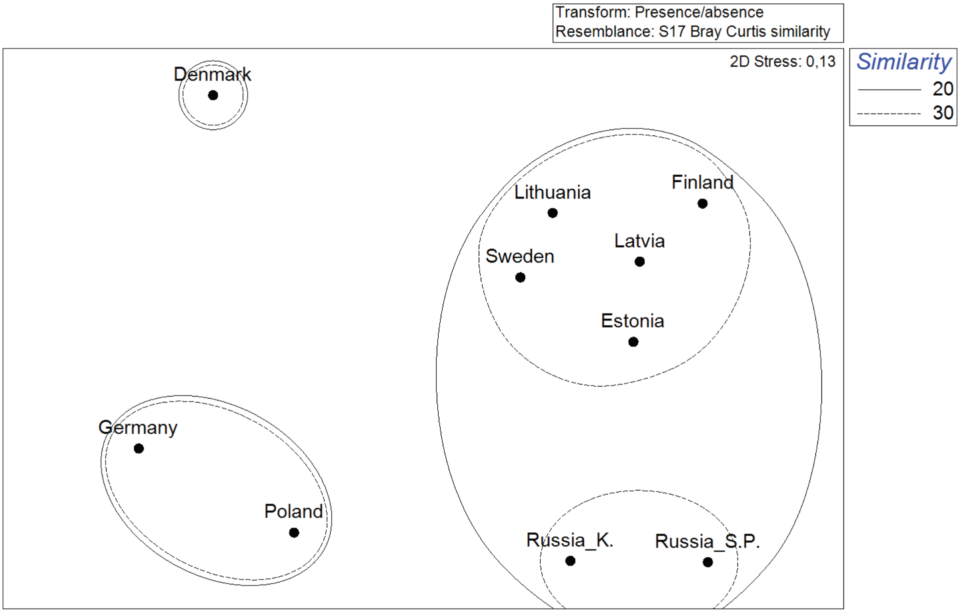


Figure 18. nMDS analysis of taxonomic similarity of NIS in the Baltic Sea during the period 2000 – 2018.

18 pav. Taksonominis introdukcijos įvykių panašumas Baltijos jūroje 2000 – 2018 m. laikotarpiu.

The similarity of new arrivals between the Baltic Sea countries at the countries level (*nNIS* = L1) showed that among 75 taxa introduced during the period 2000 – 2018, three-four major regional clusters are: 1) the south-western part (Denmark); 2) Germany and Poland similar hydrological conditions; 3) the Baltic proper and Northern Baltic countries, lower salinity (Fig. 18). It seems that species distribution is based on the salinity gradient of the Baltic Sea.

***Table 12.* Spearman rank correlation analysis of the *nNIS* index values and additional assessment based on countries level (*nNIS* = L1)**

***12 lentelė. nNIS* indekso verčių Spearmeno koreliacijos analizė šalies lygiu (*nNIS* = L1)**

r	Coastline (km)	Total number of ports	Number of ports (container liner)	Number of monitoring stations	Salinity range	Temperature range
nNIS (L1) (2000-2018)	0.51**	0.39 ns	0.55**	0.74*	0.33 ns	0.28 ns

ns – not significant; *P<0.05, **P<0.01

Secondly, the *nNIS* values were additionally analyzed with patterns and factors which could explain high or low values of *nNIS* on countries level (*nNIS* = L1). Using Spearman rank correlation *nNIS* values were compared with country coastline length, the total number of ports in a country, number of ports in a country which has a container liner, number of monitoring stations (HELCOM 2018), salinity and temperature range (Annex 6). Spearman rank correlation (Table 12; was tested for the whole period (2000 – 2018). The results showed that at the regional scale (country level), the number of *nNIS* correlated positively with the number of monitoring stations and the number of ports (container liner), the coastline distance (km), but did not correlate either with temperature or salinity range.

4.3.3 Pathways of introductions and uncertainty of the new arrivals

The spread from the neighboring countries and shipping from the North Sea can be considered to be responsible for the most of the currently widespread NIS. Other possible pathways include canals, culture activities and aquarium trade.

The analysis at the level of the Baltic Sea countries (*nNIS* = L1) for the period 2010 – 2018 reveals two main pathways of introductions: “Natural spread from the neighboring regions” (38%) and “Vessels” (37%). The pathway “Culture activities” involving the vectors aquaculture equipment, stock movements, releases and escapes, was ascribed for 7% of the primary introductions (Fig. 19).

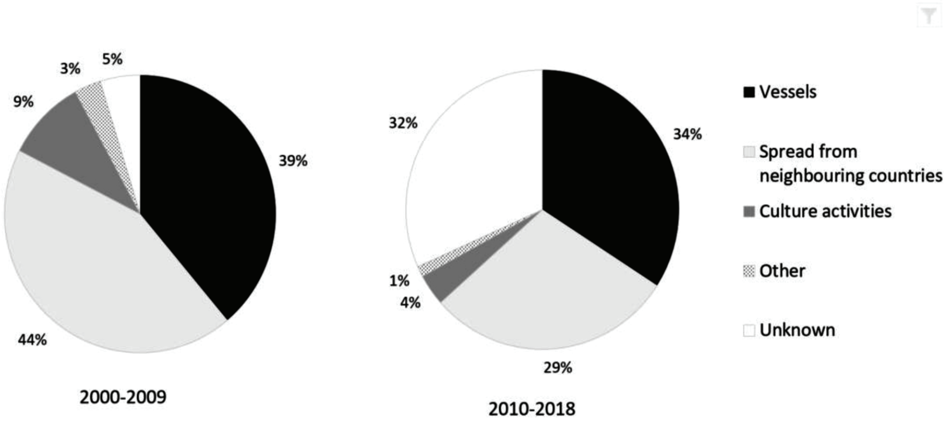


Figure 19. Pathways of non-indigenous species introduction in the Baltic Sea during periods 2000 – 2009 and 2010 – 2018

19 pav. Svetimkraščių rūšių atplitimo keliai ir vektoriai į Baltijos jūrą 2000 – 2009 ir 2010 – 2018 laikotarpiais

The comparison between two periods revealed decrease in the last period (2010 – 2018) in the introduction through vessels (39% and 34%) and neighboring countries 44% and 29%, while such pathways as "Culture activities" and "Other" decreased slightly. In the last period the high increase of pathways on the category "unknown" was seen (from 5% to 32%).

At the scale of a larger biogeographical region, covering two neighboring LMEs (L3), eleven and six (accordingly 2000 – 2009 and 2010 – 2018) species were found to be new for both seas, while others were known earlier from the North Sea and may have spread from there to the Baltic Sea.

The knowledge on the actual pathway being responsible for NIS remains low. The level of certainty in affiliating the responsible pathway for primary introduction requires special attention. It appears that only in 14 % cases (21 out of the total 149 introduction events) the introduction pathway is known with the highest level of confidence, meaning there is direct evidence of it.

In 21% of the cases, the pathway could be assigned at a relatively high confidence level (highly likely), while in the majority cases (52%) confidence levels can be described as "possible" pathways. Ten primary inoculations, involving ballast water, ballast tank sediments, hull fouling, etc. (AquaNIS 2019; Annex 5), with levels of certainty ranging from "Direct evidence" (cnidarian *Diadumene lineata*) to "Very likely" (*H. invalida, G. japonica, P. (Mesomysis) intermedia, R. cuneata*) were primary introductions.

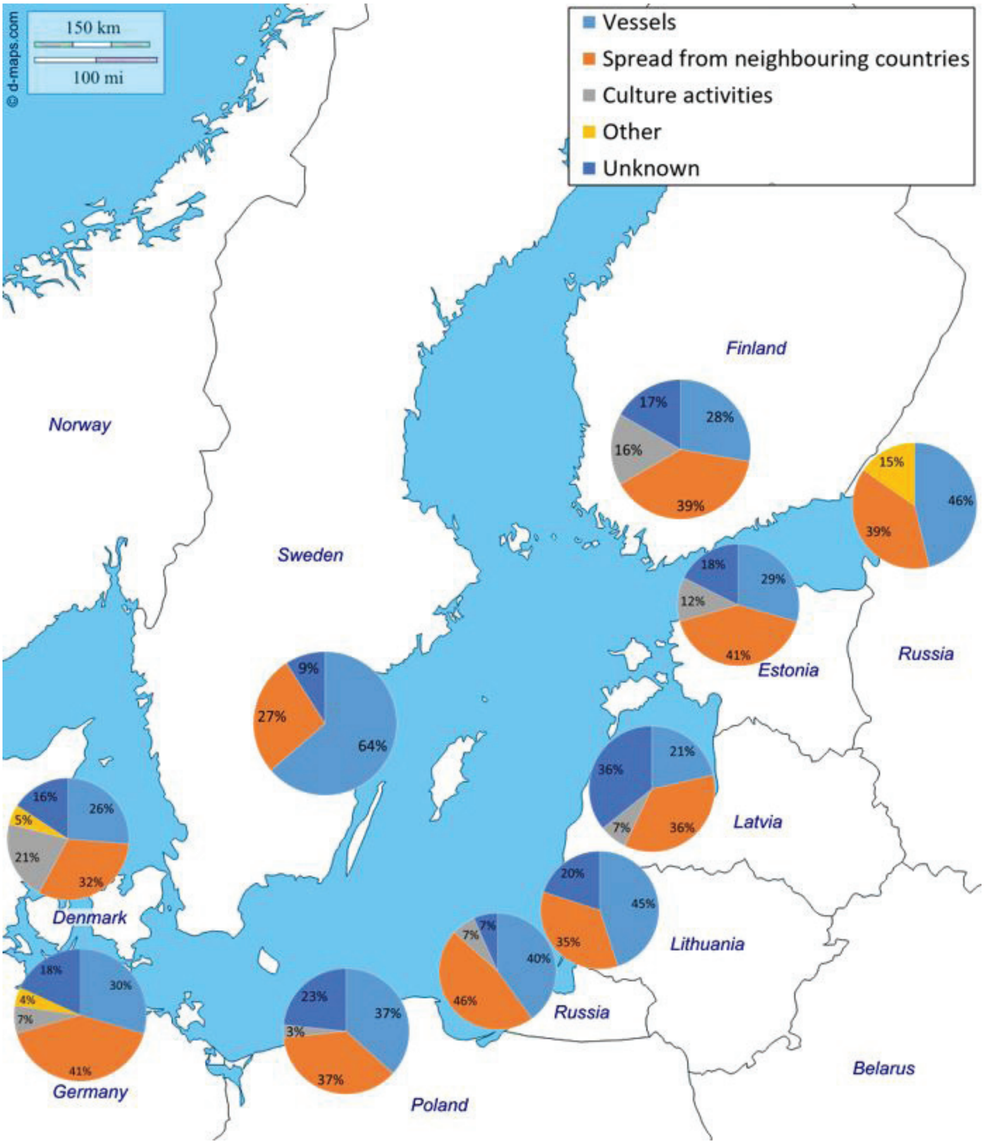


Figure 20. The percentage distribution by pathways of non-indigenous species introduction into the Baltic Sea countries during the period 2000 – 2018.

20 pav. Svetimkraščių rūšių atplitimo į Baltijos jūros šalis, kelių ir vektorių, procentinis pasiskirstymas 2000 - 2018 laikotarpiu.

According to the analysis in each country the percentage distributions of pathways are almost homogenic with vessels and a natural spread as dominating pathways, while in Sweden and Russia S.P dominating pathway is shipping. In addition, the analysis of introduction pathways by country level revealed that countries with high number of *nNIS* values (*nNIS* L1_Germany = 24 and *nNIS* L1_Poland = 13, see Table 11) have a similar distribution of introduction pathways as well as other countries with low number of NIS (*nNIS* L1_Lithuania = 3 and *nNIS* L1_Rusia_K. = 2) (Fig. 20).

4.4 Measuring the invasiveness of introduced species

4.4.1 Comparative analysis of selected NIS based on expansion rate

10 species having available geo-referenced data were selected out of 75 NIS which were involved in the introduced events during the period 2000 – 2018 (Annex 7; 8; 9). The gathered data represented five phylum and six classes. The most common species belonged to the Arthropoda (30 %), followed by Annelida and Mollusca, Chordata accordingly.

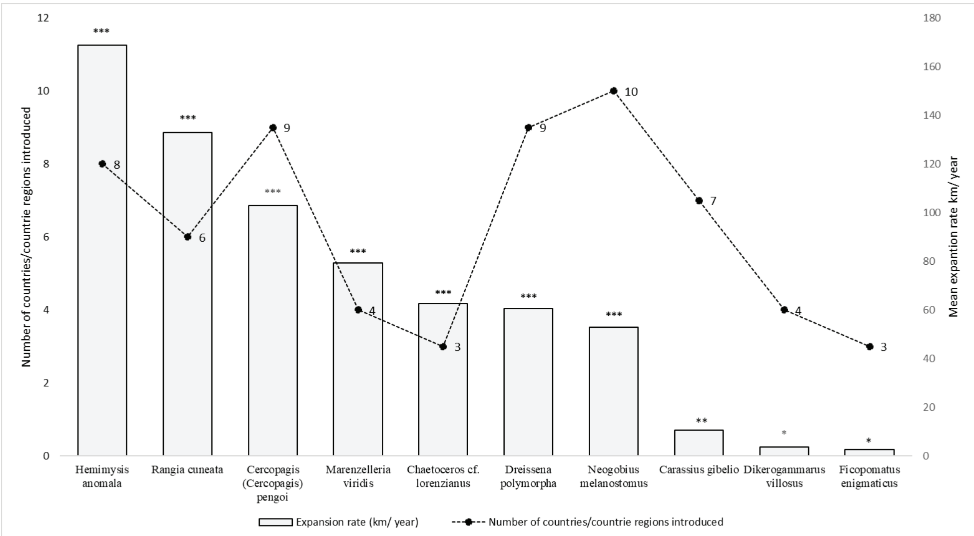


Figure 21. Comparison between mean expansion rate (km/year) and countries or regions non-indigenous species is introduced. Invasion potential subcategory *** - high; ** - moderate; * restricted.

21 pav. Lyginamoji analizė tarp rūšių vidutinio plitimo greičio (km per metus) ir šalių ar regionų skaičiaus, kuriose rūšys yra introdukuotos. Invazyvumo potencialo kategorija *** - aukšta; ** - vidutinė; * ribota.

The highest speed was counted for mysid (*H. anomala*) 168 km/year accordingly, the lowest speed was detected for Australian tubeworm (*Ficopomatus enigmaticus*) and killer shrimp (*Dikerogammarus villosus*) (Fig. 21). MER values and the data accumulated in AquaNIS (2019) were used to test the hypothesis: how species can be grouped according to the mean expansion rate. 7 out of 10 species were categorized as having high invasion potential (see Sandvik et al. 2013), one species had moderate and two species − restricted invasion potential. According to the analysis of MER rates by phylum, the arthropod and mollusk had the highest rates, while the spread was lower for annelids and chordata species.

The correlation analysis between the variables: the expansion rate and number of country/countries regions (in the Baltic Sea) where species are introduced showed relatively weak (r= 0,36) correlation, so the species ability to spread into countries cannot be compared to the actual expansion speed. This implies, that the invasion potential should not be measured as the number of countries introduced, as it represents geopolitical distribution, and does not show the level of organism ability to expand.

In order to test if NIS salinity tolerance range is a limiting factor for the spread, NIS were categorized according to the information on the number of salinity zones where species are able to reproduce and spread. The number of salinity zones was based on the Venice salinity system (see Annex 6; 7). The number of the salinity zones was compared with the invasion potential categories (Fig. 22).

The distinguished invasion potential categories for ten selected species were compared with their salinity tolerance ranges expressed in the number of the Venice salinity zones where these species occur (Fig. 22). It was found that the species with wider salinity tolerance range (from limnetic to mesohaline) generally have a higher invasion potential.

The comparison between the values of MER by NIS having pelagic stage and without pelagic stage revealed that NIS having pelagic stage had lower mean expansion rate, than NIS without pelagic stage (Fig. 23), although these results cannot be taken into account as the number of data representing results is low.

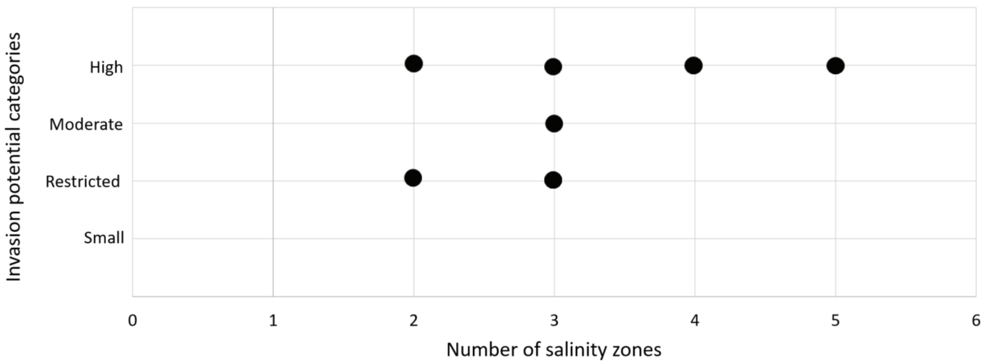


Figure 22. The non-indigenous species with different invasion potential categories (high, moderate, restricted, small) and number of salinity tolerance zones.

22 pav. Svetimkraščių rūšių pasiskirstymas pagal invazyvumo kategorijas ir druskingumo zonų skaičių.

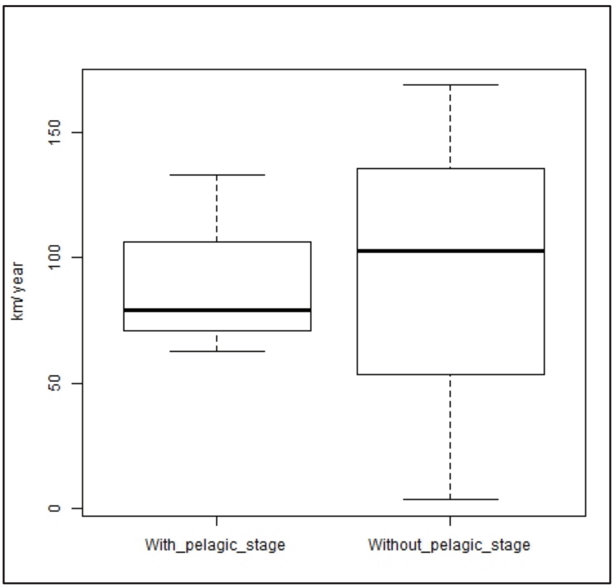


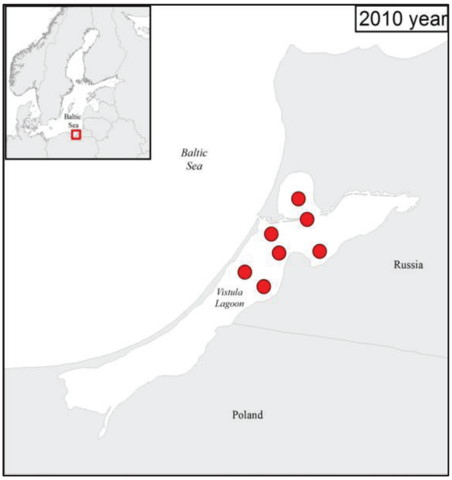
Figure 23. The average MER between NIS having pelagic stage and without pelagic stage

23 pav. Svetimkraščių rūšių vidutinio plitimo vertės tarp rūšių turinčių pelaginę stadiją ir be jos.

4.4.2 Assessment of natural and anthropogenic spread of ***Rangia cuneata***

In order to test MER application on different geographical scales, the data on the recently introduced clam was used. MER method was applied in order to determine the invasion potential for the wedge clam *Rangia cuneata* which arrived to the Baltic Sea since 2010. The data set consisted of occurrences in the Vistula lagoon (n=159) and Baltic Sea (n=333) (Fig. 24). These water bodies are different in size and environmental conditions. On the scale of the entire Baltic Sea the mean expansion rate for the clam *R. cuneta* was counted as 133 km/year (2010 – 2016), the maximum expansion distance in kilometers was 763 km. Meanwhile in the Vistula Lagoon the rate was equal to 16 km/year (2010-2014), presumably caused by natural means. During the first three years in the lagoon the rate reached about 20 km/year, after six years of expansion in the Vistula lagoon, the highest rate of expansion was 50 km/year (Fig. 24-25).

The spread in the LME of the Baltic Sea for period 2010-2016 the mean expansion rate was 70 km/year. In first three years the rate exceeded 60 km, after six years of the expansion in the Baltic Sea the rate of the expansion was equal to 600 km.

a) 

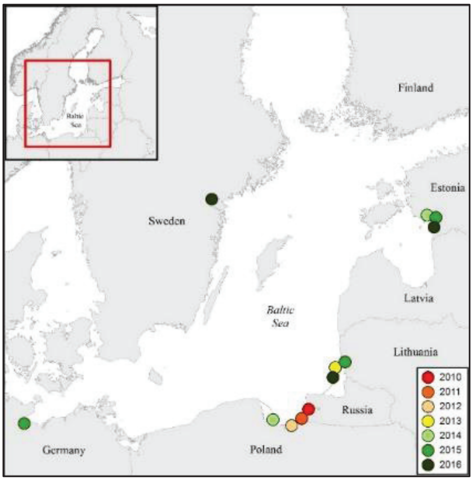
b) 

Figure 24. Current distribution of the clam *R. cuneata* in the Vistula Lagoon (a) and Baltic Sea (b).

24 pav. Dvigeldžio moliusko *R.cuneata* pasiskirstymas Vistulos lagūnoje (a) ir Baltijos jūroje (b)

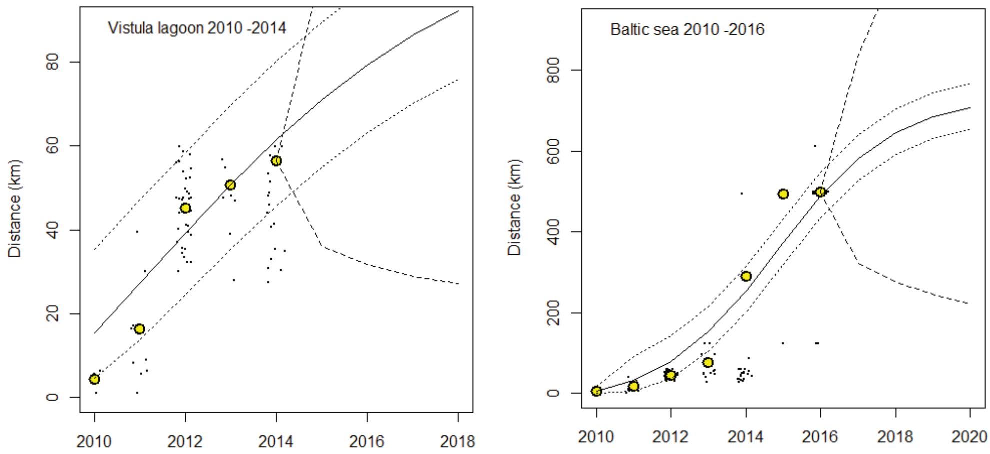


Figure 25. Linear regression model of spread with regression line and 95% confidence intervals of *R. cuneata* (a) Vistula lagoon (n=195), (b) Baltic Sea (n=333)

25 pav. R. cuneata plitimo (a) Vistulos lagūnoje (n=195), b) ir Baltijos jūroje (n=333) tiesinės regresijos modelis su 95% pasikliautiniu intervalu

According to the different spread speed of *R. cuneata* in the water bodies, it is presumed that the spread value in the Vistula lagoon represents the natural spread of species, while the value of the spread in the Baltic Sea is eight times higher, it may be explained by the spread implicated by the anthropogenic spread or human-mediated actions, such as ballast water or any waterborne transport associated with human activities.

5

Discussion

5.1 Quality of the risk and impact assessment methods

5.1.1 Key principles of risk assessment process

The two legislative documents reviewed in this study were developed for different purposes: while the EU regulation (European Union) has a wide spectrum of application and addresses the invasive alien species of all taxa and within all habitats, the IMO Guidelines (IMO) focuses on harmful aquatic organisms and pathogens transferred by a single vector of introduction. However, the cross-comparison of both documents highlighted the common features that stem from their overall orientation on biosecurity. Such a comparative analysis is especially needed nowadays when EU countries are to implement both legally binding instruments, the BWMC (IMO 2004), which entered into force in 2017 (IMO 2017) and the EU the Regulation on the prevention and management of the introduction and spread of invasive alien species (Union European 2014). The comparison of the related risk assessment frameworks (IMO 2007 and European Union 2018) helps to achieve a more comprehensive, integrative view on the risk assessment process. As the result, the approach developed in this study is based on three criteria. The key principles and assessment components form the basic criteria in the risk assessment, while the categories of the bioinvasion impacts are complimentary and add to the completion of the full evaluation procedure. This is because such impacts were not specified in either analyzed document.

The screening of similar regional and international regulations and frameworks, e.g. Convention on Biological Diversity (CBD 2011), North America Free Trade Agreement (General Accounting Office, GAO), Asia-Pacific Economic Cooperation (Williamson et al. 2002), ICES Code of Practice on the Introductions and Transfer of marine organisms (2005) do not reveal different criteria which have been examined. Barry et al. (2008), Dahlstrom et al. (2011) and David and Gollasch (2015) who analyzed biosecurity risk assessment regulatory documents and bioinvasion risk and impact assessment methods also did not reveal criteria other than have been used. It would seem that the key principles and RA components are universal for the evaluation of bioinvasion risk and methods. The categories of the bioinvasion impacts may vary depending on the scope of the assessment and should be used as complimentary criteria.

The consistency between the methods should result in accurate and consistent impact scores for a species even if applied by different assessors, however, despite the importance of consistency in impact and risk assessment methods, there is little understanding of the patterns in consistency of impact scores across assessors and protocols, and, more importantly, which factors contribute to high levels of consistency. The level of the consistency in values across assessors may depend not only on the characteristics of the protocol (e.g. taxonomic and environmental scope, impact types included), but also on the available scientific evidence of the impact, and the level of expertise of assessors. For instance, if a high consistency (i.e. low impact score variability) across assessors for well-studied species is expected, or when all assessors have an in-depth understanding of the species under consideration (Gonzalez-Moreno et al. 2019).

The compliance of risk and impact assessment method with the key principles shows the quality of a method. The analysis showed that only three methods made their assessment tools and documentation available via an online database. This must be considered the highest „Transparency'' level and an example for other methods to follow. This is because decision-makers should have access to the full information to be able to compare the usage of bioinvasion risks and impacts assessment methods in similar situations worldwide.

Online information sources for NIS already exist for specific areas, e.g. for prioritizing most impacting NIS (e.g. target species lists), defining their pathways and vectors and with recommendations for their management (Olenin et al. 2014). Lehtiniemi et al. (2015) have stated that there is little value in monitoring of NIS unless the knowledge obtained is timely and can be directly used. The importance of dissemination of information, the transparency principle, was stressed many times at international and national levels (e.g. Awad et al. 2014; Sing and Tan 2018). In addition, the availability of the information is important to achieve "a uniform high level of performance, using a common process and methodology" (IMO 2007).

5.1.2 The BWM Convention and three assessment approaches

Environmental matching of risk assessment. Methods AI-ISK, GB NNRA, HARMONIA+, CMIST and TRAAIS have some principles of the "environmental matching of risk assessment" aspects. Noting that all methods describe and compare the similarity differently, there are a couple of similar tendencies. AI-ISK considers environmental tolerance limits of species such as temperature, methods for the similarity of environmental conditions use the Australian climate match method CLIMATCH (Barry et al. 2008), which generates the possibility to check the similarities between the introduction and native region in a sense of temperature. The method CMIST has some similarities of included parameters such as suitable conditions for the establishment considering environmental tolerance limits for conditions (temperature, salinity, turbidity) and suitable habitat for non-native species.

GB NNRA considers questions of likelihood of survival and establishment. The question of survival considers the survival of species during the passage in the ballast water and in the invaded area. Other aspects of environmental conditions overviewed in this method are climatic conditions and abiotic conditions. It also should be mentioned that the questions that are directly considered are the similarity between the native and invaded regions of invasive species.

Some methods consider indirect aspects of environmental conditions similarity; e.g. GABLIS considers environmental tolerance limits, taking into account the conditions of reference area or original distribution area with the ecologically similar area. Methods which do not consider any environmental similarity aspects during the assessment are BINPAS, GISS, GISS IUCN, GEIAA, CIMPAL.

Species biogeographical risk assessment. A less incorporated aspect into the risk/impact assessment methods is the biogeographical risk assessment. This aspect which considers the number of non-native species in an area, compares the biogeographical distributions of nonindigenous species that presently exist in the donor and recipient ports and biogeographic regions. Most of the methods do not consider the question how many biogeographic regions the species has spread directly. It should be noted that some methods like GB NNRA reveal the assessment including the questions such as how many EU member states this species has established. A special attention is paid to the species distribution in other regions; it is indirectly assessed by the methods such as AI-ISK, CMIST, HARMONIA+, GEIAA, TRAAIS. None of the methods assess the distribution or number of records in the recipient region as an indicator, nor quantifies it. Another general indicator of risk would be if the donor biogeographic region is a major source of invaders to other areas.

Species-specific risk assessment. Four methods out of fifteen include biological traits for assessment, i.e. AI-ISK, CMIST, GEIAA, GABLIS, while all methods include impacts on environment, less methods have categories on economic (HARMONIA+)

and human health categories. Both aspects (biological traits and impact categories) of assessment were included in the methods such as: AI-ISK, GEIAA, GB NNRA, GABLIS. The risk assessment toll of AI-ISK fully includes all "species – specific" aspect, it assesses biological traits, environmental tolerance limits of species and impacts. GEIAA also includes almost all aspects although some biological traits that are considered are different. GEIAA assesses biological traits such as reproduction strategy, reproduction capacity, generation time, expected population lifetime, expansion velocity; it uses statistics and modeling to assess these features. The method assesses the impacts of species, but only to the environment. GB NNRA assesses biological traits, environmental tolerance limits of species (probability of entry, establishment, spread) and impacts (environmental, economic, human health) indirectly.

Specifically, the potential of invasiveness as one of the questions was also included. The methods assess the potential of invasiveness differently, e.g. GEIAA uses the mean expansion rate to count the speed of the spread. Although the BINPAS, CIMPAL methods do not include the potential of invasiveness or other biological traits of species, but it includes the impact categories into the assessment. The inclusion of biological traits differs, the main questions: GISS methodology takes into account only the impacts on the environment and economy, it does not include the biological traits, environmental tolerance limits. GABLIS indirectly includes biological traits (reproduction capacity, spread capacity), environmental tolerance limits (reference area or original distribution area, ecologically similar area).

5.1.3 Policy relevance of the risk and impact assessment methods

All bioinvasion risk and impact assessment methods reviewed here have been designed to support management decisions in a manner consistent with recommendations from multiple publications, e.g.: the method allows "a comparison and thus a prioritization of species" (Nentwig et al. 2010), "enables an effective priorization of management efforts" (Sandvik et al. 2013), "identification of hotspots areas, and prioritization of sites, pathways and species for management actions" (Katsanevakis et al. 2016), "inform management and policy decisions" (Drolet et al. 2016). Consequently, the methods should conform to the policy documents involved. In this study, the policy relevance may be defined as usefulness of a method for those who make decisions on biosecurity.

An approach developed in this study may help in choosing the most appropriate method, for example, to test the policy relevance of a method for the implementation of the BWMC. While only one method purposefully designed for the BWMC was analyzed in our study (RABW), several other methods may be used for the BWMC purposes with the adjustment, should they follow the key principles and take into account RA components. For example, the GB NNRA method covers such components as NIS spread, pathways, distribution and impacts, which are needed when considering a risk assessment of ballast water (Behrens 2005; Werschkun et al. 2014; Olenin et al. 2016). It is noteworthy that the method integrating most of the RA components (SBRA) was especially designed for one of the shipping vectors, i.e., for the species biofouling risk assessment (Hewitt et al. 2011).

Ideally, all methods should comply with the key principles and RA components as far as possible, while the bioinvasion impact categories may vary and should be selected according to the purpose of the RA. For example, the risk to human health is an important issue (Conn 2014), however not all methods, even those purposefully designed for BWMC take into account this impact category. In the earlier study by Barry et al. (2008) only two out of the eight reviewed "ballast water risk assessment systems" refer to the importance of human health categories without considering any details. Generally, the study has shown that more attention is paid to the environmental impacts rather than to human health or economic impacts.

A large-scale marine biodiversity assessment problem pointed out by the European Commission, in their evaluation of the EU member states' reports on the MSFD initial assessments carried out in 2010-2012 (Galil et al. 2013; Palialexis et al. 2014). Despite the available guidance and Commission Decision (European Union 2010) on GES descriptors, criteria and indicators, the overall picture in assessments was patchy and non-coherent (European Commission 2014). A coherent assessment framework can be used to evaluate differences in the environmental status and the ecological components that are impacted by different pressures.

5.2 New arrivals as a measure of effectiveness of legal and administration instruments

5.2.1 Defining the assessment size and effectiveness of measures

The size of the assessment unit for the *nNIS* index may vary depending on the practical considerations, management needs and data availability. In this case, the assessment unit was equal to a country marine area within an LME (Baltic Sea) or LME sub-region. Such subdivision is determined because the management decisions on preventive measures are taken at the level of national authorities. The smallest possible level would be a port and/or its vicinities, were biological surveys in ports are obligatory, for example, for taking a decision on granting exemptions under BWMC (David et al. 2013a, Galil et al. 2014; David and Gollasch 2015; Olenin et al. 2016), but currently not all countries are obliging to share the monitoring information, and as a consequence the information at the ports level is scarce. Although NIS distribution makes changes to their biogeographical boundaries, in order to manage them it requires the sharing of information between countries, agencies within countries, non-governmental bodies, citizen groups and researchers.

Data on the introduction of alien species is always a problematic case. The species identifications, uncertain records or unknown pathways or impacts complicate the assessment of NIS. However, the molecular tools (Zaiko et al. 2015; Bucklin et al. 2016; Raupach et al. 2016; Viard et al. 2016), combined with a rising scientific concern are contributing to improve the quality of the current species records (Olenin et al. 2016).

While it is challenging to recreate the past history of introductions of species due to human intervention (Carlton 2009; Clavero et al. 2014), now modern records of new arrivals are conveyed with more in-depth analysis of possible vectors and detailed knowledge on NIS (e.g. Reusch et al. 2010). While according to this study results in the last nine years the knowledge on introduced NIS on origin, impacts, and pathways decreased.

A perspective indicator of new arrivals (*nNIS*) could supply information essential for early warning (Magalleti et al. 2018), horizon-scanning programs (sensu Roy et al. 2014) and identification of an environmental target for the MSFD Good Environmental Status (GES) descriptor 2 "*Non-indigenous species*" (MSFD 2008/56/EC). Further, such an indicator enables an assessment how effective implemented vector and pathway management measures are.

Considering *nNIS* index as a tool for environmental measures and their effectiveness, the following patterns should be taken into account: a) *nNIS*, as such, has little information without further analysis of pathways and vectors involved in the spread of new species; b) Different pathways/vectors are subject to different management options, e.g. vectors "Ballast water" and "Regional stock movement" can be manageable, while "Natural spread" is not; c) An environmental target should be defined for primary introduction at L2 or higher level, because introductions at L1 may be a result of the secondary spread.

5.2.2 The limitations and advantages of the ***nNIS*** index

The AquaNIS database is used in this study because it is regularly updated by the ICES Working Group on Introductions and Transfers of Marine Organisms, for now it is the only database that can provide data needed for *nNIS* index. The technical advantages of the *nNIS* calculation are the availability of a verified and continuously updated source of information on introduction events. The results of this study show that the average number of new arrivals in the past two decades in the Baltic Sea region is changing over time. These assessments could not be performed without a reliable database, which can be achieved only by a continuous work of data checking and updates of introduction events (Olenin et al. 2016). Without continuous maintenance, update and data quality control, the usefulness of the database reduces over time and could give misleading information (Costello and Vanden Berghe 2006; Olenin et al.

2014; 2016). Indicator *nNIS* is a value for recipient region or LME, where regular NIS surveys or well-established long-term biological monitoring is maintained (Olenin et al. 2011; Lehtiniemi et al. 2015).

It has to be taken in mind that in some cases the ability to distinguish between the primary introduction and secondary spread may be limited. The multiple introductions of NIS from outside an LME area are also possible. One of the examples of multiple introductions is the American comb jelly *Mnemiopsis leidyi* that is "very-likely" to spread via ballast waters from two distinct source populations from the western Atlantic to the Black Sea and the North Sea (Reusch et al. 2010). Multiple introductions make distinctions between the primary introduction and secondary spread within an LME or larger biogeographical region more difficult. The development of eDNA techniques could assist in determining the origin in the future (Rius et al. 2015; Solovjova et al. 2019).

However, the control or eradication of NIS without affecting other components of the ecosystem is feasible after an invasion process or when species has become established. Given the severity of problems that can be caused by biological invasions, it is mandatory for the policy and management to focus on the pathways and vectors with the aim to prevent further introductions (e.g. EU IAS Regulation 2014).

This indicator could serve also as a measurement of marine environmental status at the regional or international level. For Lithuanian marine area, it may be formulated as "*No new primary introductions of NIS by ship's ballast water to the Baltic Sea via territory of Lithuania for the assessment period*", i.e. the environmental target is: "*nNIS* L2_Lithuania (by ballast water) = 0". In this case, the environmental target will be achieved if during the assessment period no NIS, new for the entire Baltic Sea, entered the marine area under jurisdiction of Lithuania by ship ballast water. Thus, only primary introductions at the level of entire LME (L2) are counted, i.e. the secondary spread is excluded. Based on this formulated task, taking into account the assessment periods, the target was reached for periods 2000 – 2009 and 2010 – 2018 the indicator *nNIS* on the level of country (L2) was equal to zero (*nNIS* L2_Lithuania (by ballast water) = 0), meaning no introduction events during 2000-2018 were detected in the level of L2 (Baltic Sea).

The environmental target may be harmonized at the level of LME or a larger region, including several neighbouring LMEs, where secondary dispersal of NIS may take place with currents and other natural means. For example, the Baltic Sea Action Plan (HELCOM 2007) sets the environmental management objective "*No introductions of alien species from ships*". The management of primary introductions at the scale L2 and L3 is crucial, because the secondary spread, which can be inevitable, may strongly limit the ability for any practical regulation. The reason for that is a further spread which may involve the dispersal by the same pathway or by multiple pathways that might act.

While the records of introduction events are higher than the number of species, it is explained that once species get introduced into the Baltic Sea, it spreads through the secondary spread and does not count as a new species in the region. Most species were introduced firstly in the Baltic Sea region, and then species spread through the secondary spread within the Baltic Sea region. All secondary spreads, in this case, will be counted as an introduction event. Although the analysis of introduction events showed that in the 2000 – 2009 period there were 79 introduction events, while in 2010 – 2018 the number of introductions decreased to 69 events.

What is not possible to manage are the natural processes involving tidal movements, alongshore drift and other aquatic biota as a carrier of NIS either within an LME or from neighbouring LME. The proposed new arrivals indicator is clearly associated with anthropogenic pressure in terms of specific pathways/vectors involved and this may help to prioritize management actions. The Regional Sea Conventions were attempting to harmonize the MSFD indicators, and new arrivals (*nNIS*) have strong applicable patterns which could be used for environmental status assessments (e.g. HELCOM 2012). The same method may be applicable within the terrestrial realm, where the lower the number of new NIS arrivals the better has been the invasive species management (e.g. EU IAS Regulation 2014).

5.3 Distinguishing between natural and anthropogenic spread of NIS

5.3.1 The power of biological traits or ballast water

The dynamics underlying the invasion are affected by a large number of parameters, such as density regulation in space and time, growth rate, patterns of expansion, demographic and environmental stochasticity (Kot et al. 1996; Neubert and Caswell 2000; Freckleton et al. 2006; Lewis et al. 2006; Sandvik et al. 2013). In order to identify the dynamics of NIS in the Baltic Sea regions, these parameters were analyzed directly and indirectly in this study. These parameters are needed in order to have a good description of the mechanisms of expansion of an alien species in a new environment (e.g., Veit and Lewis 1996). While sometimes the expansion potentially could be overestimated while trying to explain natural spread using the numbers of countries NIS are introduced, what is relevant for the risk assessment of alien species is an estimate of the expected speed with which the species has reached and will reach previously uncolonised areas (Sandvik et al. 2013).

The predominant biological profile of typical NIS in the Baltic Sea region was species which has ability to develop through spawning or brooding, have a pelagic larval stage and has wide salinity range from limnetic to mesohaline, with high invasion potential.

So far there is a limited number of methods to measure the spread of species especially when it comes to the comparison of NIS according to their spread or measure of their invasiveness. The most common measure of invasiveness is counting the countries where the species were detected (Molnar et al. 2008; Olenin et al. 2016), other authors propose to count the number of regions occupied (Goodwin et al. 1999), a very common approach is to define the bioregions or ecoregions NIS are spread into. Other authors claim that the characteristics of NIS and their interactions with species within a new locality determine how widespread the NIS will become. Some remain relatively localized around the point of introduction, whereas others can spread widely. The distinction between these two groups of species is very hard and sometimes even not possible.

All taxonomic groups of NIS analyzed in this study for testing MER were recorded in the ballast water tanks worldwide (Gollasch et al, 2002; Drake and Lodge 2007; Wu et al. 2017; Cabrini et al. 2018). One of the hypotheses tested in this study, was that a species with the entire life cycle in the water column compared to the one having short pelagic life stages has more ability to be transported with ballast water through vessels. Higher MER values between taxonomic species were found, although the differences between these two groups, rather than between species having the pelagic stage or without it were estimated. The data showed that this method can be applied for the invasiveness in order to compare species and their invasion potential, but clear data of occurrences should be used.

As accumulated data on the spread of species varied between taxon and phyla, some patterns have emerged, that there are differences between NIS with pelagic stage and without, still more factors considering larval types species correlation with ballast water is needed.

The larval dispersal is one of the most important topics in marine ecology, as marine invertebrates and many fish have a bi-phasic life cycle with a pelagic larva or pelagic eggs that can be transported over long distances (Grosberg and Levitan 1992). The diversity in the ballast tanks varies from pathogens, bacteria, isopods, mysids, bivalves, gastropods, and fish, especially at larval stages (Gollasch et al. 2002). Once the species is established within a new locality the species remain restricted to a small region, it was assumed that the spread is limited because of their short larval period or not having a larval stage (Leppakoski et al. 2013). Marine organisms with larva, most of them release larvae into the water column, where they develop before transforming into adults. Planktotrophic larvae are for a long time in the water column and recruit successfully with low probability, these organisms release huge numbers of larvae to increase the chances that at least one will survive. Sessile and sedentary organisms such as barnacles, tunicates, and mussels require a mechanism to move their young into a new territory, since they cannot move long distances as adults. Many species have relatively long pelagic larval durations on the order of weeks or months. These factors also can be crucial for primary and secondary spread of NIS in new environments.

The different models and assumptions result in different estimates of both expected population lifetime (e.g., Shigesada and Kawasaki 1997; Hooten and Wikle 2008) and additional data is needed for interpretation of results. After the introduction of species into new environment and establishment, NIS can spread into new surroundings (Bobeldyk et al. 2005; Zanden and Olden 2008; Simkanin et al. 2009), as the secondary spread of NIS is more crucial due to the fact it cannot be controlled. However, the classification of the spread using MER can help to distinguish species in order quantitatively assess the spread of NIS.

5.3.2 Natural and anthropogenic dispersal

To clarify the application patterns and effectiveness of MER method we assessed the invasive potential of the clam in the Baltic Sea and semi-enclosed system Vistula lagoon (Poland). The comparison of the spread in two water bodies revealed the differences in the spread values of the clam *Rangia cuneata* in the Baltic Sea region and the lagoon.

The native origin of the common clam *R. cuneata* (G.B. Sowerby I, 1832) (Bivalvia, Mactridae) is within the Gulf of Mexico. It is spreading within North European brackish waters (AquaNIS 2019; Verween et al. 2006). It was first found in Belgium during 2005 (Verween et al. 2006) and has since has spread to the estuaries in southern regions of the North Sea (Neckheim 2013; Bock et al. 2015; Gittenberger et al. 2015; Wiese et al. 2016; Kerckhof et al. 2018;). It entered the South-Eastern Baltic Sea about 2010, in the waterway leading to the port of Kaliningrad, the Vistula Lagoon region in Russia (Ezhova 2012; Rudinskaya and Gusev 2012). In 2011 it was recorded in the Polish part of the Vistula Lagoon (Warzocha and Drgas 2013; Janas et al. 2014; Warzocha et al. 2016). It was in 2013 when it was recorded at an early stage along Lithuanian coastal waters (Solovjova 2014), and further to the North in Pärnu Bay, Gulf of Riga, Estonia (Möller and Kotta 2017). Later on it was found in Poland, Germany, Lithuania, Estonia, and Sweden waters (AquaNIS 2019).

While the average currents in the Baltic Sea are weak with average speeds of 5 cm/s, during storms, wind drift currents can reach 50 m/s, in straits up to 100 cm/s (Snoeijs-Leijonmalm et al. 2017). Although, the marine bivalve larvae can disperse over long distances, determining the actual distance is challenging because of their size and the lack of a good tracking method. According to Sundberg the larvae viability of *R. cuneata* is 7 days (Sundberg and Kennedy 1993). Taking into account the average current speed, for seven days a larva can travel for approx. 30 km; during storm event this can make up to 300 km, provided that the currents are stable and unidirectional. Based on these calculations it may be presumed that in the Vistula lagoon the spread was natural, while according to high MER for the whole Baltic Sea the natural spread is very unlikely.

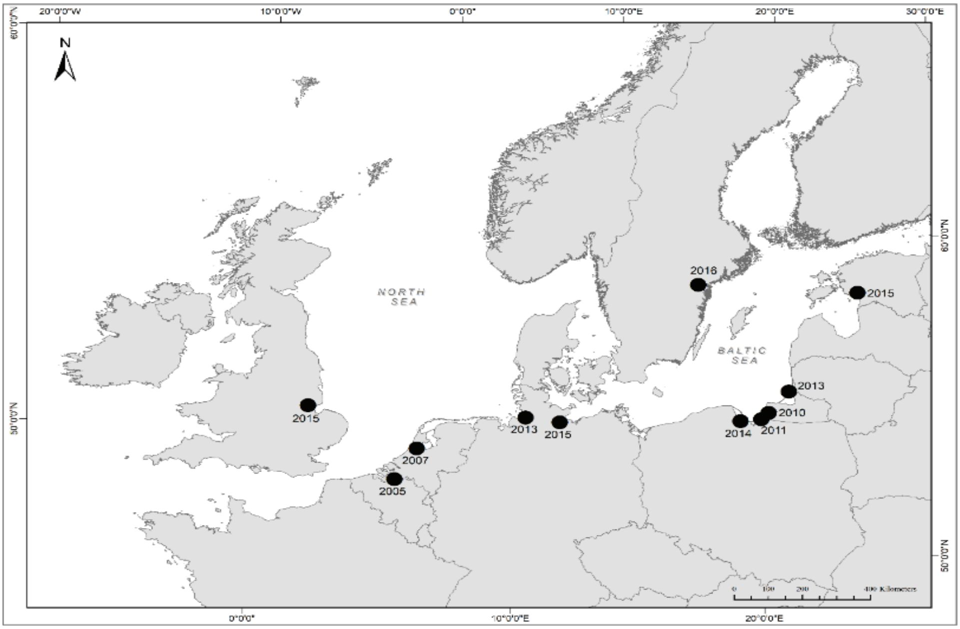


Figure 26. Map of current distribution of clam *R. cuneata* in northern Europe with indication of the year of the first record.

26 pav. Dvigeldžio moliusko *R. cuneata* paplitimo šiaurinėje Europoje žemėlapis nurodant pirmo aptikimo metus.

Before 2013 the non-indigenous clam was not found in any station of Lithuanian coast and the Curonian lagoon. The occurrences of this species can be explained by the port excavation activities in 2008, where equipment for excavation was brought from the Netherlands (Verween et al. 2006). Other possibility to explain the occurrence of the *Rangia cuneata* in Lithuanian waters is its natural spread from neighboring countries (Poland or the Russian Federation) (Warzocha and Drgas 2013; Janas et al. 2014; Warzocha et al. 2016). The latest records from Estonia, the Parnu bay (Möller and Kotta 2017) and Sweden (unpublished data, AquaNIS) shows the ability of the clam to spread further to the Northeast part of the Baltic Sea (Fig. 26).

Although it should be noted that *Rangia cuneata* was not found in the plankton samples using barcoding in 2014 (Ardura et al. 2015). Also rangia was not found in shell deposits on the beach until August 2017, a species may be overlooked, including both method rapid assessment and barcoding. It was first found in the open sea area closed to the Kaliningrad district area waters. This implies the hypothesis for natural dispersal (no shipping lanes, no ballast water operations included).

The large number of parameters needed in order to provide a good description of the mechanisms of expansion of an alien species in a new environment (e.g., Veit and Lewis 1996) cannot normally be estimated from the data on the spread alone. Data on local population dynamics, how these co-vary in time, and how individuals spread are required, too. Very few datasets with such a level of detail are available so far (Sandvik et al. 2013).

6

Conclusions

1. The comparative analysis of the EU Invasive Alien Species Regulation regarding risk assessments in relation to invasive alien species (2018, No 968/2018) and the IMO Guidelines for Risk Assessment Under Regulation A-4 (2007) revealed that the criteria for the evaluation of the bioinvasion impact and risk assessment methods should be based on the eight key risk assessment (RA) principles, 29 RA components and four main types of impacts (human health, economical, environment and social-cultural values). Based on the above criteria the relevant framework was developed.

2. The evaluation of 15 selected bioinvasion impact and risk assessment methods allowed concluding that the closer the method is complying with the key principles ("Transparency", "Consistency", "Comprehensiveness", etc.) the higher is its quality. Also, the quality of the method depends on the fullness of involvement of the RA components, while the bioinvasion impact categories may vary and should be selected according to the scope of the RA. Concerning the categories of impacts, all methods considered at least one category of environmental impacts (100%), followed by impacts on economy (60%) and human health (57%), while the social-cultural values got least attention (53%).

3. The analysis revealed that while none of the methods fully complied with all criteria, the Australian SBRA (Species Biofouling Risk Assessment) method got the highest score, followed by the Belgian HARMONIA+ and the British AS-ISK meth-

ods. The developed criteria and evaluation framework may be recommended for the assessment of future methods.

4. The application of the *nNIS* index revealed that the number of the primary introductions at the level of the larger biogeographical region (Baltic Sea + North Sea, *nNIS* L3) has declined from 9 during 2000-2009 to 6 during 2010-2018, while the number of species new for the entire Baltic Sea region (*nNIS* L2) has increased from 20 to 25. This implies that the interregional exchange of previously introduced species, i.e. secondary introductions, is increasing. Also, the pathway analysis based on *nNIS* showed that “Spread from neighboring countries” and “Vessels” remains the most important reasons of non-indigenous species introductions in the Baltic Sea region (44% and 29%; 39% and 34%, during two periods, respectively).

5. The application of the Mean Expansion Rate (MER) method allowed distinguishing the most spreading NIS, the mysid *Hemimysis anomala*, among selected ten species the Baltic Sea with the MER=168 km/year. Generally, species with pelagic stages and wide salinity tolerance range had the higher MER. The natural spread, determined for the invasive bivalve clam *Rangia cuneata* was MER=16 km/year in the area of the primary introduction, the Vistula Lagoon, while at the scale of the entire Baltic Sea it was MER=133 km/year, implying the human-mediated transportation.

6. The *nNIS* index is a useful parameter for environmental status assessments (e.g., HELCOM Holistic Assessment, 2018) and as a measure of the effectiveness of the environmental policy aimed at prevention of new introductions. The MER method is an effective way to measure invasiveness, which compliments the definition of invasiveness based on the assessment of impacts of invasive species. The combination of these two methods (*nNIS* and MER) may be useful for prioritization of management actions provided that additional information on pathways/vectors involved in spread of new species is accessible through a global information system, such as AquaNIS.

7

References

1. AquaNIS (2019) "Editorial board," in Information System on Aquatic Non-Indigenous and Cryptogenic Species (World Wide Web electronic publication). Version2.36+. Available onlineat: http://www.corpi.ku.lt/databases/aquanis. (Accessed January, 2019).
2. Allendorf FW, Leary RF, Spruell P et al (2001) The problems with hybrids: setting conservation guidelines. Trends in ecology & evolution, 16:613–622
3. Arbaciauskas K (2005) The distribution and local dispersal of ponto-caspian peracarida in lithuanian fresh waters with notes on Pontogammarus robustoides population establishment, abundance and impact. Oceanological and Hydrobiological Studies, 34 (1): 93-111 pp.
4. Ardura A, Zaiko A, Martinez JL, Samulioviené A, Semenova A, Garcia-Vazquez E (2015) eDNA and specific primers for early detection of invasive species - a case study on the bivalve *Rangia cuneata*, currently spreading in Europe. Marine Environmental Research, 112 (B), 48-55, http://dx.doi.org/10.1016/j.marenvres.2015.09.013.
5. Awad A, Haag F, Anil AC, Abdulla A (2014) GEF-UNDP-IMO Globallast partnerships programme, IOI, CSIR and IUCN Guidelines on Port Biological baseline Surveys. GEFUNDP-IMO Globallast Partnerships, London, UK. Globallast Monograph No 22, 48.

6. Bailey S, Jelmert A, Minchin D, Sneekes A (2014) Non-native species risks to the Arctic. ICES CM 2014/F:0
7. Bacher S, Blackburn TM, Essl F, Genovesi P, Heikkilä J, Jeschke JM et al. (2018) Socio-economic impact classification of alien taxa (SEICAT). Methods in Ecology and Evolution 9: 159–168. https://doi.org/10.1111/2041-210X.12844
8. Baker RHA, Black R, Copp GH, Haysom KA, Hulme PE, Thomas MB et al. (2008) The UK risk assessment scheme for all non-native species. Neobiota, 7, 46-57.
9. Barney JN, Schenk T, Haak DC, Salom S, Brown B, Hotchkiss ER (2019) Building Partnerships and Bridging Science and Policy to Address the Biological Invasions Crisis. Invasive Plant Science and Management, 1-5.
10. Barry SC, Hayes KR, Hewitt CL, Behrens HL, Dragsund E, Bakke SM (2008) Ballast water risk assessment: principles, processes, and methods. ICES Journal of Marine Science 65.2, 121-131.
11. Bax N, Williamson A, Aguero M, Gonzalez E, Geeves W (2003) Marine invasive alien species: a threat to global biodiversity. Marine policy, 27(4), 313-323.
12. Behrens J, van Deurs M, Christensen E AF (2015) Salinity tolerance and correlated physiology of the invasive round goby Neogobius melanostomus. In ICES Annual Science Conference 2015.
13. Behrens HL, Haugom GP, Mordal Bakke S (2002) EMBLA Concept: Risk Assessment Methodology and Impact and Consequence Methodology Scheme. DNV Report, Det Norske Veritas, Hövik, Norwegen. 24 pp
14. Behrens HL, Leppäkoski E, Olenin S (2005) Ballast water risk assessment guidelines for the North Sea and Baltic Sea. Nordic Innovation Centre NT TECHN REPORT, 587, 2005-12.
15. Benejam L, Aparicio E, Vargas MJ, Vila-Gispert A, García-Berthou E (2008) Assessing fish metrics and biotic indices in a Mediterranean stream: effects of uncertain native status of fish. Hydrobiologia, 603(1), 197-210.
16. Bellard C, Thuiller W, Leroy B, Genovesi P, Bakkenesk M, Courchamp F (2013) Will climate change promote future invasions? Global Change Biology 19: 3740–3748. https://doi.org/10.1111/gcb.12344
17. Bellard C, Leclerc C, Leroy B, Bakkenes M, Veloz S, Thuiller W, Courchamp F (2014) Vulnerability of biodiversity hotspots to global change. Global Ecology and Biogeography, 23(12), 1376-1386.
18. Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, Kumschick S, Marková Z, Mrugała A, Nentwig W, Pergl J, Pyšek P, Rabitsch W, Ricciardi A, Richardson DM, Sendek A, Vilà M, Wilson JRU, Winter M, Genovesi P, Bacher S (2014) A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts. PLoS Biology 12. DOI: 10.1371/journal.pbio.1001850.

19. Bobeldyk AM, Bossenbroek JM, Evans-White MA, Lodge DM, Lamberti GA (2005) Secondary spread of zebra mussels (Dreissena polymorpha) in coupled lakestream systems. Ecoscience 12: 339-346.
20. Bochert R (1997) Marenzelleria viridis (Polychaeta: Spionidae): a review of its reproduction. Aquatic Ecology, 31(2), 163-175.
21. Bock G, Lieberum C, Schütt R, Wiese V (2015) Erstfund der Brackwasser-muschel *Rangia cuneata* in Deutschland (Bivalvia: Mactridae). Schriften zur Malakozoologie, 28, 13-16.
22. Borja A, Franco J, Valencia V, Bald J, Muxika I, Belzunce M J, Solaun O (2004) Implementation of the European water framework directive from the Basque country (northern Spain): a methodological approach. Marine Pollution Bulletin, 48(3-4), 209-218.
23. Borja A (2005) The European water framework directive: A challenge for near-shore, coastal and continental shelf research. Continental Shelf Research 25 1768–1783
24. Borja A, Elliott M, Uyarra MC, Carstensen J and Mea M (2017) Bridging the gap between policy and science in assessing the health status of marine ecosystems. Frontiers in Marine Science, 4, 32.
25. Born W, Rauschmayer F, Bräuer I (2005) Economic evaluation of biological invasions—a survey. Ecological Economics, 55(3), 321-336.
26. Bouchemousse S, Lévêque L, Dubois G, Viard F (2016) Co-occurrence and reproductive synchrony do not ensure hybridization between an alien tunicate and its interfertile native congener. Evolutionary Ecology, 30(1), 69-87.
27. Booy O, Cornwall L, Parrott D, Sutton-Croft M, Williams F (2017) Impact of biological invasins on infrastructure. In Vilà M, Hulme PE (Eds) Impact of biological invasions on ecosystem services. Springer International, Cham, 235–247. https://doi.org/10.1007/978-3-319-45121-3_15
28. Boxshall GA, Mees J, Costello MJ, Hernandez F, Gofas S, Hoeksema BW, Klautau M, Kroh A, Poore GCB, et al. (2014) World Register of Marine Species. Available from,http://www.marinespecies.org (at VLIZ. Accessed 2014-11-07).
29. Bucklin A, Lindeque PK, Rodriguez-Ezpeleta N, Albaina A and Lehtiniemi M (2016) Metabarcoding of marine zooplankton: prospects, progress and pitfalls. Journal of Plankton Research, 38,393–400.doi:10.1093/plankt/fbw023
30. Butchart SH, Walpole M, Collen B, Van Strien A, Scharlemann JP, Almond R. E. et al. (2010) Global biodiversity: indicators of recent declines. Science, 328(5982), 1164-1168.
31. Breine J, Simoens I, Goethals P, Quataert P, Ercken D, Van Liefferinghe C., Belpaire C (2004). A fish-based index of biotic integrity for upstream brooks in Flanders (Belgium). Hydrobiologia, 522(1-3), 133-148.

32. Cabrini M, Cerino F, de Olazabal A, Di Poi E, Fabbro C, Fornasaro D. et al. (2018) Potential transfer of aquatic organisms via ballast water with a particular focus on harmful and non-indigenous species: A survey from Adriatic ports. Marine Pollution Bulletin.
33. Campbell AC, Ormond RF (1970) The threat of the 'crown-of-thorns' starfish (*Acanthaster planci*) to coral reefs in the Indo-Pacific area: Observations on a normal population in the Red Sea. Biological Conservation, 2(4), 246-251.
34. Cardeccia A, Marchini A, Occhipinti-Ambrogi A, Galil B, Gollasch S, Minchin D, Narščius A, Olenin S, Ojaveer H (2018) Assessing biological invasions in European Seas: Biological traits of the most widespread non-indigenous species. Estuarine, Coastal and Shelf Science, 1-12
35. Carlton JT (2001) Introduced species in US coastal waters: environmental impacts and management priorities. Arlington, Virginia: Pew Oceans Commission.
36. Carlton JT (2009) Deep invasion ecology and the assembly of communities in historical time, in Biological Invasions in Marine Ecosystems, (eds) Rilovand G, Crooks JA (Berlin; Heidelberg: Springer-Verlag), 13-56.
37. Cassey P, Delean S, Lockwood JL, Sadowski JS, Blackburn TM (2018) Dissecting the null model for biological invasions: A meta-analysis of the propagule pressure effect. PLoS Biol 16(4): e2005987. https://doi.org/10.1371/journal.pbio.2005987
38. CBD (1992) Convention on Biological Diversity. Secretariat of the Convention on Biological Diversity. United Nations environment program. Available online at: https://www.cbd.int/doc/legal/cbd-en.pdf
39. CBD (2011) Convention on Biological Diversity. Conference of the Parties Decision X/2: Strategic plan for biodiversity 2011–2020. The Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available from www.cbd.int/decision/cop/?id=12268 (accessed January 2019).
40. Ciruna KA, Meyerson LA, and Gutierrez A (2004) The ecological and socio–economic impacts of invasive alien species in inland water ecosystems. Washington, DC: Convention on Biological Diversity
41. Clarke C, Hayes T, Hilliard R, Kayvan Rad N, Taymourtash H, Parhizi A, Yavari V, Raaymakers S (2003) Ballast water risk assessment, Port of Khark Island, Islamic Republic of Iran., August 2003: Final Report. GloBallast Monogrpah Series No.8, IMO London (http://globallast.imo.org/).
42. Clavero M (2014) Shifting baselines and the conservation of non-native species. Conservation Biology. 28,1434–1436.doi:10.1111/cobi.12266
43. Cohen AN and Carlton JT (1998) Accelerating invasion rate in a highly invaded estuary. Science, 279(5350), 555-558.
44. Coleman RR, Gaither MR, Kimokeo B et al (2014) Large-scale introduction of the Indo-Pacific damselfish *Abudefduf vaigiensis* into Hawai'i promotes ge-

netic swamping of the endemic congener *A. abdominalis*. Molecular Ecology, 23:5552–5565

45. Coles SL, De Felice RC, Eldridge LG, Carlton JT (1999) Historical and recent introductions of non-indigenous marine species into Pearl Harbor, Oahu, Hawaiian Islands. Marine Biology, 135: 147–58
46. Collen BEN, Loh J, Whitmee S, McRAE L, Amin R, Baillie JE (2009) Monitoring change in vertebrate abundance: the Living Planet Index. Conservation Biology, 23(2), 317-327.
47. Corkum LD, Sapota MR, Skóra KE (2004) The round goby Neogobius melanostomus, a fish invader on both sides of the Atlantic Ocean. Biol Invasions 6: 173-181
48. Costello MJ, Vanden Berghe E (2006) "Ocean Biodiversity Informatics" enabling a new era in marine biology research and management. Marine Ecology Progress Serie. 316, 203-214.
49. Costello MJ, Appeltans W, Bailly N, Berendsohn W G, de Jong Y, Edwards M, Segers H (2014) Strategies for the sustainability of online open-access biodiversity databases. Biological Conservation 173, 155-165.
50. COP (2002) Review and consideration of options for the implementation of article 8(h) on alien species that threatens ecosystems, habitats or species. Conference of the parties to the Convention on Biological Diversity (COP). UNEP/CBD/COP/6/18/Add.1/Rev.1. 26-3-2002.
51. Copp GH, Bianco PG, Bogutskaya NG, Erős T, Falka I, Ferreira MT (2005) To be, or not to be, a non-native freshwater fish? Journal of Applied Ichthyology, 21(4), 242-262.
52. Copp GH, Vilizzi L, Mumford J, Fenwick GV, Godard MJ, Gozlan RE (2009) Calibration of FISK, an invasive-ness screening tool for non-native freshwater fishes. Risk Analysis 29:457-467 DOI 10.1111/j.1539-6924.2008.01159.x.
53. Copp GH (2013) The Fish Invasiveness Screening Kit (FISK) for non-native freshwater fishes: A summary of current applications. Risk Analysis, 33(8), 1394-6.
54. Copp GH, Vilizzi L, Tidbury H, Stebbing P, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. Management of Biological Invasions 7:343-350. DOI 10.3391/mbi.2016.7.4.04.
55. Courchamp F, Fournier A, Bellard C, Bertelsmeier C, Bonnaud E, Jeschke JM, Russel JC (2017) Invasion biology: specific problems and possible solutions. Trends in Ecology and Evolution 32: 13–22. https://doi.org/10.1016/j.tree.2016.11.001
56. Covich AP, Palmer MA, Crowl TA (1999) The Role of Benthic Invertebrate Species in Freshwater Ecosystems: Zoobenthic species influence energy flows and nutrient cycling. BioScience Vol. 49 No. 2. 119-127pp.

57. Crall AW, Meyerson LA, Stohlgren TJ, Jarnevich CS, Newman GJ, Graham J (2006) Show me the numbers: what data currently exist for non-native species in the USA? Frontiers in Ecology and the Environment 4: 414–18
58. Crowl TA, Crist TO, Parmenter RR, Belovsky G, Lugo AE (2008) The spread of invasive species and infectious disease as drivers of ecosystem change. Frontiers in Ecology and the Environment, 6(5), 238-246.
59. Dahlstrom A, Hewitt CL, Campbell ML (2011) A review of international, regional and national biosecurity risk assessment frameworks. Marine Policy, 35(2), 208-217.
60. Dargahi B, Kolluru V, Cvetkovic V (2017) Multi-layered stratification in the Baltic Sea: insight from a modeling study with reference to environmental conditions. Journal of Marine Science and Engineering, 5(1), 2.
61. Dana ED, Jeschke JM, Garcia-de-Lomas J (2014) Decision tools for managing biological invasions: existing biases and future needs. Oryx 48: 56-63.
62. David M, Perkovič M (2004) Ballast water sampling as a critical component of biological invasions risk management. Marine Pollution Bulletin, 49(4), 313-318.
63. David M and Gollasch S (ed) (2015) Global Maritime Transport and Ballast Water Management: Issues and Solutions. Invading Nature, Springer Series in Invasion Ecology 8, 13–34. Dordrecht: Springer Science C Business Media.
64. David M, Gollasch S, Pavliha M (2013a) Global ballast water management and the “same location” concept: a clear term or a clear issue? Ecological Applications 23(2), 331-338
65. David M, Gollasch S, Leppäkoski E (2013b) Risk assessment for exemptions from ballast water management–the Baltic Sea case study. Marine pollution bulletin 75(1-2), 205-217.
66. David P, Thebault E, Anneville O, Duyck PF, Chapuis E, Loeuille N (2017) Impacts of invasive species on food webs: a review of empirical data. In Advances in ecological research 56, 1-60, Academic Press.
67. Davidson IC, Scianni C, Minton MS, Ruiz GM (2018) A history of ship specialization and consequences for marine invasions, management and policy. Journal of applied ecology, 55(4), 1799-1811.
68. Davis MA (2006) Invasion biology 1958–2005: the pursuit of science and conservation. In: Cadotte MW, McMahon SM, Fukami T (eds) Conceptual ecology and invasion biology. Springer, Berlin
69. Davis MA (2009) Invasion Biology. Oxford; New York, NY: Oxford University Press on Demand.
70. De Lange WJ and van Wilgen BW (2010) An economic assessment of the contribution of biological control to the management of invasive alien plants and to the protection of ecosystem services in South Africa. *Biological Invasions*, *12*(12), 4113-4124.

71. Devictor V, Van Swaay C, Brereton T, Brotons L, Chamberlain D, Heliölä J et al. (2012) Differences in the climatic debts of birds and butterflies at a continental scale. Nature climate change, 2(2), 121.
72. Dickey JWE, Cuthbert RN, Rea M, Laverty C, Crane K, South J. et al. (2018) Assessing the relative potential ecological impacts and invasion risks of emerging and future invasive alien species. NeoBiota 40: 1-24.
73. Didham RK, Tylianakis JM, Hutchison MA, Ewers RM, Gemmell NJ (2005) Are invasive species the drivers of ecological change? Trends in ecology & evolution, 20, 470-474.
74. Drake JM and Lodge DM (2006) Allee effects, propagule pressure and the probability of establishment: risk analysis for biological invasions. Biological Invasions, 8(2), 365-375.
75. Drake JM and Lodge DM (2007) Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. Aquatic Invasions, 2(2), 121-131.
76. Drolet D, Locke A, Lewis MA, Davidson J (2014) User-friendly and evidence-based tool to evaluate probability of eradication of aquatic non-indigenous species. Journal of Applied Ecology 51:1050-1056.
77. Drolet D, Locke A, Lewis MA, Davidson J (2015) Evidence-based tool surpasses expert opinion in predicting probability of eradication of aquatic nonindigenous species. Ecological Applications 25:441-450.
78. Drolet D, DiBacco C, Locke A, McKenzie CH, McKindsey CW, Moore AM, Webb JL, Therriault TW (2016) Evaluation of a new screening-level risk assessment tool applied to non-indigenous marine invertebrates in Canadian coastal waters. Biological Invasions 18:279-294.
79. D'hondt B, Vanderhoeven S, Roelandt S, Mayer F, Versteirt V, Adriaens T. et al. (2015) Harmonia + and Pandora+: risk screening tools for potentially invasive plants, animals and their pathogens. Biological Invasions 17:1869-1883. DOI: 10.1007/s10530-015-0843-1.
80. Early R, Bradley BA, Dukes JS, Lawler JJ, Olden JD, Blumenthal DM. et al. (2016) Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications, 7, 12485.
81. EEA (2007) European Environment Agency. Climate Change and Water Adaptation Issues, EEA Technical Report No. 2/2007, Copenhagen, 110.
82. Elliott M, Ducrotoy JP (Eds.) (1991) Estuaries and coasts: spatial and temporal intercomparisons (Vol. 19). Olsen & Olsen.
83. Elton Charles S (2000) The ecology of invasions by animals and plants. University of Chicago Press.
84. Essl F, Nehring S, Klingenstein F, Milasowszky N, Nowack C, Rabitsch W (2011) Review of risk assessment systems of IAS in Europe and introducing

the German-Austrian Black List Information System (GABLIS). Journal for Nature Conservation 19:339–350. DOI: 10.1016/j.jnc.2011.08.005.
85. Essl F, Bacher S, Genovesi P, Hulme PE, Jeschke JM, Katsanevakis S. et al. (2018) Which taxa are alien? Criteria, applications, and uncertainties. BioScience, 68(7), 496-509.
86. Emerton L and Howard G (2008) A toolkit for the economic analysis of invasive species. Nairobi: Global Invasive Species Programme. Nairobi, 100 p
87. European Community (2005) Common implementation strategy for the water framework directive (2000/60/EC) Overall Approach to the Classification of Ecological Status and Ecological Potential. WFD CIS Guidance Document No. 13.
88. European Commission (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Off. J.Eur.Union L 164,19-40.
89. European Commission (2010) Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010)5956)(2010/477/EU). Off.J.Eur. UnionL 232,12–24.
90. European Commission (2014) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive aliens pecies. Off.J. Eur. Union 57,35.
91. European Commission (2018) Regulation (EU) No 968/2018 of the European Parliament and of the Council of 30 April 2018 supplementing Regulation (EU) No 1143/2014 of the European Parliament and of the Council with regard to risk assessments in relation to invasive alien species.
92. Evans J, Barbara J, Schembri PJ (2015) Updated review of marine alien species and other 'newcomers' recorded from the Maltese Islands (Central Mediterranean). Mediterranean Marine Science, 16(1), 225-244.
93. Ezhova EE (2012) New alien species in the Baltic Sea - the clam *Rangia cuneata* (Bivalvia: Mactridae). Mar. Ecol. J. 11 (1), 29—32, (in Russian).
94. Faasse M and van Moorsel G (2003) The North-American amphipods, *Melita nitida* Smith, 1873 and *Incisocalliope aestuarius* (Watling and Maurer, 1973) (Crustacea: Amphipoda: Gammaridea), introduced to the Western Scheldt estuary (The Netherlands). Aquatic Ecology, 37(1), 13-22.
95. Freckleton RP, Watkinson AR, Green RE and Sutherland WJ (2006) Census error and the detection of density dependence. Journal of Animal Ecology, 75(4), 837-851.
96. Galil B, Occhipinti-Ambrogi A, Marchini A (2013) East is east and west is west–implications of bioinvasion patterns in the mediterranean sea for implementation of the MSFD. Rapp. Comm. int. Mer Médit, 40, 594.

97. Galil BS, Marchini A, Occhipinti-Ambrogi A, Minchin D, Narščius A, Ojaveer H, Olenin S (2014) International arrivals: widespread bioinvasions in European Seas. Ethology Ecology and Evolution, 26(2-3), 152-171.
98. Gallien L, Münkemüller T, Albert CH, Boulangeat I, Thuiller W (2010) Predicting potential distributions of invasive species: where to go from here? Diversity and Distributions, 16(3), 331-342.
99. Gallopin GC (1996) Environmental and sustainability indicators and the concept of situational indicators. A systems approach. Environmental modeling and assessment, 1(3), 101-117.
100. Gassner H, Wanzenböck J, Zick D, Tischler, G and Pamminger-Lahnsteiner B (2005) Development of a fish based lake typology for natural Austrian lakes> 50 ha based on the reconstructed historical fish communities. International Review of Hydrobiology: A Journal Covering all Aspects of Limnology and Marine Biology, 90(4), 422-432.
101. GAO (2002) General Accounting Office. Invasive Species Clearer Focus and Greater Commitment Needed to Effectively Manage the Problem. GAO Report No. -03-1, Wash. D.C.
102. Genovesi P and Shine C (2004) European strategy on invasive alien species: Convention on the Conservation of European Wildlife and Habitats (Bern Convention) (No. 18-137). Council of Europe.
103. Gilroy JJ, Avery JD, Lockwood JL (2017) Seeking international agreement on what it means to be "native". Conservation Letters 10: 238–247.
104. Gittenberger A, Rensing M, Dekker R, Niemantsverdriet P, Schrieken N, Stegenga H (2015) Native and non-native species of the DutchWadden Sea in 2014. Report nr.: GiMaRIS 2015_08. 94 pp
105. Gollasch S (2007) International collaboration on marine bioinvasions – the ICES response. Marine Pollution Bulletin, 55, 353-359. doi:10.1016/j.marpolbul.2006.11.009
106. Gollasch S, Macdonald E, Belson S, Botnen H, Christensen JT, Hamer J. et al. (2002) Life in ballast tanks. pp. 217-231. Invasive Aquatic Species of Europe - Distribution, Impact and Management.
107. González-Moreno P, Lazzaro L, Vilà M, Preda C, Adriaens T, Bacher S, Srėbalienė G et al. (2019) Consistency of impact assessment protocols for non-native species. NeoBiota, 44: 1-25.
108. Goodwin BJ, McAllister AJ, Fahrig L (1999) Predicting invasiveness of plant species based on biological information. Conservation biology, 13(2), 422-426.
109. Grosholz ED, Ruiz GM., Dean CA, Shirley KA, Maron JL, Connors PG (2000) The impacts of nonindigenous marine predator in California Bay. Ecology 81: 1206-1224.

110. Grosholz E (2002) Ecological and evolutionary consequences of coastal invasions. Trends in ecology & evolution, 17(1), 22-27.
111. Grosberg RK and Levitan DR (1992) For adults only? Supply-side ecology and the history of larval biology. Trends Ecol. Evol. 7: 130-133.
112. Goodwin BJ, McAllister AJ, Fahrig L (1999) Predicting invasiveness of plant species based on biological information. Conservation biology, 13(2), 422-426.
113. Hayes KR and Hewitt CL (2000) Risk assessment framework for ballast water introductions–Volume II. Centre for Research on Introduced Marine Pests Technical Report, (21), 188.
114. Hewitt CL and Hayes KR (2001) Marine biosecurity and risk assessment. In: Quarantine and Market Access Conference Proceedings; Oct. 2001; [Canberra, ACT]. Biosecurity Australia; 2001. 176-182.
115. Haugom GP, Behrens HL, Andersen AB (2002) Risk based methodology to assess invasive aquatic species in ballast water. In Invasive aquatic species of Europe. Distribution, impacts and management (pp. 467-476). Springer, Dordrecht.
116. HELCOM (2007) *BSAP. The HELCOM Baltic Sea Action Plan,* Vol.15. Krakow: HELCOM.
117. HELCOM (2012) Development of a set of core indicators: Interim report of the HELCOM CORESET project. PARTB: descriptions of the indicators," in BaltSea Environment Proceedings No.129B (Helsinki).
118. HELCOM (2018) State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155. (Helsinki).
119. Hewitt CL (2006) Alien species in aquaculture: considerations for responsible use. IUCN.
120. Hewitt CL, Campbell ML, Thresher RE, Martin RB, Boyd S, Cohen BF et al. (2004) Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. Marine Biology, 144(1), 183-202.
121. Hewitt C, Richard L, Everett A, Parker N (2009) Examples of current international, regional and national regulatory frameworks for preventing and managing marine bioinvasions, in Biological Invasions in Marine Ecosystems, Vol.335, Ecological Studies 204, (eds) Rilovand G, Crooks JA (Berlin; Heidelberg: Springer-Verlag), 335-352.doi:10.1007/978-3-540-79236-9_19
122. Hewitt CL, Campbell ML, Rawlinson N, Coutts ADM (2011) Vessel biofouling risk assessment. Report for the Department of Agriculture, Fisheries and Forestry, National Centre for Marine Conservation 8.
123. Higgins SN and Vander Zanden MJ (2010) What a difference a species makes: a meta-analysis of dreissenid mussel impacts on freshwater ecosystems. Ecological Monographs 80:179–196.

124. Hooten MB and Wikle CK (2008) A hierarchical Bayesian non-linear spatio-temporal model for the spread of invasive species with application to the Eurasian Collared-Dove. Environmental and Ecological Statistics, 15(1), 59-70.
125. IMPRESS (2003) Common implementation strategy for the Water Framework Directive (2000/60/EC), guidance document 3, analysis of pressures and impacts. Office for Official Publications of the European Communities, Luxembourg. Available via http://circa.europa.eu/Public/ irc/env/wfd/library 135:195–216.
126. IUCN (1999) IUCN/SSC Criteria Review Working Group. IUCN Red List Criteria review provisional report: draft of the proposed changes and recommendations.
127. ICES (2005) ICES Code of Practice on the Introductions and Transfers of Marine Organisms, Vol.30. Copenhagen: ICES.
128. ICES (2014) Manual for the Mackerel and Horse Mackerel Egg Surveys (MEGS): Sampling at Sea. Series of ICES Survey Protocols. Copenhagen: ICES.SISP6-MEGSV1.3.62.
129. ICES (2016) Report of the Working Group on Introductions and Transfers of Marine Organisms (WGITMO). Olbia: ICESCM2016/SSGEPI:10.201.
130. IMO (2004) International Convention for the Control and Management of Ships' Ballast Water and Sediments, Vol.36. IMO.BWM/CONF/36 (London: IMO).
131. IMO (2004) International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004. International Maritime Organization, 13 February 2004. International Maritime Organization, London, UK. 36.
132. IMO (2007) Guidelines for Risk Assessment Under Regulation A-4 of the BWM Convention (G7), IMO, Marine Environment Protection Committee, Resolution MEPC. 162(56), 13 2007. International Maritime Organisation, London.
133. IMO (2017) Implementation of the BWM Convention. Resolution MEPC 287(71) of 7 2017. International Maritime Organisation, London.
134. IMO (2016) International Convention for the Control and Management of Ships' Ballast Water and Sediments. Online at: http://www.imo.org/en/About/Conventions/ListOfConventions/. aspx. (Accessed 21 September, 2016).
135. Yokomizo H, Possingham HP, Thomas MB, Buckley YM (2009) Managing the impact of invasive species: the value of knowing the density–impact curve. Ecological Applications, 19(2), 376-386.
136. Janas U, Kendzierska H, Dąbrowska AH, Dziubińska A (2014) Non-indigenous bivalve—the Atlantic rangia *Rangia cuneata*—in the Wisła Śmiała River (coastal waters of the Gulf of Gdańsk, the southern Baltic Sea). Oceanological and Hydrobiological Studies, 43(4), 427-430.
137. Jarić I, Heger T, Monzon FC, Jeschke JM, Kowarik I, McConkey KR et al. (2019) Crypticity in biological invasions. Trends in ecology & evolution.

138. Jewett EB, Crooks JA, Ruiz GM (2000) Assessing the ecological impact of a non-indigenous colonial hydroid *Cordylophora caspia*, in the Chesapeake Bay. Abstracts for AERS Fall Meeting November 9-11, 2000 Smithsonian Environmental Research Center, Edgewater, MD
139. Jeschke JM, Gomez Aparicio L, Haider S, Heger T, Lortie CJ, Pyšek P, Strayer DL (2012) Taxonomic bias and lack of cross-taxonomic studies in invasion biology. Frontiers in Ecology and theEnvironment10:349–350.
140. Jeschke JM, Bacher S, Blackburn TM, Dick JT, Essl F, Evans T et al. (2014) Defining the impact of non-native species. Conservation Biology, 28(5), 1188-1194.
141. Katsanevakis S, Bogucarskis K, Gatto F, Vandekerkhove J, Deriu I, and Cardoso AC (2012) Building the European Alien Species Information Network (EASIN): a novel approach for the exploration of distributed alien species data. Bioinvasions Rec. 1, 235–245. doi: 10.3391/bir.2012. 1.4.01
142. Katsanevakis S, Coll M, Piroddi C, Steenbeek J Ben Rais Lasram F, Zenetos A, Cardoso AC (2014) Invading the Mediterranean Sea: biodiversity patterns shaped by human activities. Frontiers in Marine Science, 1, 32.
143. Katsanevakis S, Deriu I, D'Amico F, Nunes AL, Pelaez Sanchez S, Crocetta F et al. (2015) European alien species information network (EASIN): supporting European policies and scientific research. Management of Biological Invasions, 6(2), 147-157.
144. Katsanevakis S, Tempera F, Teixeira H (2016) Mapping the impact of alien species on marine ecosystems: The Mediterranean Sea case study. Diversity and Distributions, 22.6: 694-707. DOI: 10.1111/ddi.12429.
145. Keane RM, Crawley MJ (2002) Exotic plant invasions and the enemy release hypothesis. Trends in ecology & evolution, 17(4), 164-170.
146. Kerckhof F, Devleeschouwer, M, Hamers N (2018) De Amerikaanse brakwaterstrandschelp *Rangia cuneata* (G.B.Sowerby, 1832) aangetroffen in Frankrijk. De Strandvlo, 37,141-145.
147. Kilgour BW, Mackie GL, Baker MA, Keppel R (1994) Effects of salinity on the condition and survival of zebra mussels (*Dereissena polymorpha*). Estuaries, 17(2), 385.
148. Kot M, Lewis MA, van den Driessche P (1996) Dispersal data and the spread of invading organisms. Ecology, 77(7), 2027-2042.
149. Kumschick S and Nentwig W (2010) Some alien birds have as severe an impact as the most effectual alien mammals in Europe. Biological Conservation, 143.11: 2757-2762.
150. Kumschick S, Bacher S, Dawson W, Heikkilä J, Sendek A, Pluess T et al. (2012) A conceptual framework for prioritization of invasive alien species for management according to their impact. NeoBiota, 15: 69-100.

151. Latombe G, Pyšek P, Jeschke JM, Blackburn TM, Bacher S, Capinha C et al. (2017) A vision for global monitoring of biological invasions. Biological Conservation, 213, 295-308.
152. Lees AC and Gilroy JJ (2014) Vagrancy fails to predict colonization of oceanic islands. Global ecology and biogeography, 23(4), 405-413.
153. Lehtiniemi M, Ojaveer H, David M, Galil B, Gollasch S, McKenzie C, Pederson J (2015) Dose of truth—monitoring marine non-indigenous species to serve legislative requirements. Marine Policy 54, 26-35.
154. Leppäkoski E, Gollasch S, Olenin S (2013) Invasive aquatic species of Europe. Distribution, impacts and management. (Eds.) Springer Science & Business Media.
155. Leung B, Roura-Pascual N, Bacher S, Heikkilä J, Brotons L, Burgman MA, Dehnen-Schmutz K, Essl F, Hulme PE, Richardson DM, Sol D, Vila M (2012) TEASIng apart alien species risk assessments: a framework for best practices. Ecology Letters, 15(12), 1475-1493.
156. Lewis MA, Neubert MG, Caswell H, Clark JS, Shea K (2006) A guide to calculating discrete-time invasion rates from data. In Conceptual ecology and invasion biology: reciprocal approaches to nature (pp. 169-192). Springer, Dordrecht.
157. Liu TK, Chang CH, Chou ML (2014) Management strategies to prevent the introduction of non-indigenous aquatic species in response to the Ballast Water Convention in Taiwan. Marine Policy, 44, 187-195.
158. Lockwood JL, Hoopes MF, Marchetti MP (2007) Invasion Ecology. Wiley-Blackwell, Malden, MA, USA.
159. Lodge, David M, Williams, Susan; MacIsaac, Hugh J.; Hayes, Keith R.; Leung, Brian; Reichard, Sarah; Mack, Richard N.; Moyle, Peter B.; Smith, Maggie; Andow, David A.; Carlton, James T.; and McMichael, Anthony (2006) Biological Invasions: Recommendations for U.S. Policy and Management. Ecological Applications, 16, 6, 2035-2054.
160. Lowry E, Rollinson EJ, Laybourn AJ, Scott TE, Aiello-Lammens ME, Gray SM et al. (2013) Biological invasions: a field synopsis, systematic review, and database of the literature. Ecology and evolution, 3(1), 182-196.
161. Magaletti E, Garaventa F, David M, Castriota L, Kraus R, Luna GM et al. (2017) Developing and testing an early warning system for nonindigenous species and ballast water management. Journal of sea research, 133, 100-111. doi: 10.1016/j.seares.2017.03.016
162. Marchini A, Galil BS, Occhipinti-Ambrogi A (2015) Recommendations on standardizing lists of marine alien species: lessons from the Mediterranean Sea. Marine Pollution Bulletin, *101*(1), 267-273.
163. Mazaris AD and Katsanevakis S (2018) The threat of biological invasions is under-represented in the marine protected areas of the European Natura 2000 network. Biological conservation, 225, 208-212.

164. Mazza G, Tricarico E, Genovesi P, Gherardi F (2014) Biological invaders are threats to human health: an overview, Ethology Ecology & Evolution, 26:2-3, 112-129.
165. McGeoch MA, Chown SL, Kalwij JM (2006) A global indicator for biological invasion. Conservation Biology, 20(6), 1635-1646.
166. McGeoch MA, Butchart SH, Spear D, Marais E, Kleynhans EJ, Symes A et al (2010) Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Diversity and Distributions, 16(1), 95-108
167. Medcof JC (1975) Living marine animals in a ships' ballast water. Proc. Nat. Shellfish Assoc. 65, 54–55.
168. Mendoza Alfaro RE (2009) Trinational risk assessment guidelines for aquatic alien invasive species: test cases for the Snakeheads (Channidae) and Armored Catfish (Loricariidae) in North American Inland Waters.
169. Minchin D (2007) Aquaculture and transport in a changing environment: overlap and links in the spread of alien biota. Marine Pollution Bulletin, 55, 302-313.
170. Molnar JL, Gamboa RL, Revenga C, Spalding M (2008) Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment 6(9):485-492
171. Möller T and Kotta J (2017) Rangia cuneata (GB Sowerby I, 1831) continues its invasion in the Baltic Sea: the first record in Pärnu Bay, Estonia.
172. Moustakas A and Katsanevakis S (2018) Data Mining and Methods for Early Detection, Horizon Scanning, Modelling, and Risk Assessment of Invasive Species. Frontiers in Applied Mathematics and Statistics, 4, 5.
173. Narščius A, Olenin S, Zaiko A, Minchin D (2012) Biological invasion impact assessment system: From idea to implementation. Ecological Informatics 7:46_51
174. Neckheim CM (2013) Verspreding van de Brackwaterstrandschelp Rangia cuneata (Sowerby, 1831) in Nederland. Spirula 391: 37-38.
175. Nehring S, Essl F, Rabitsch W (2013a) Methodik der naturschutzfachlichen Invasivitätsbewertung für gebietsfremde Arten. Version 1:1-46.
176. Nehring S, Kowarik I, Rabitsch W, Essl F (2013b) Nature conservation risk assessment of invasive, potentially invasive and wild alien plant species in Germany. BfN-Skripten (Bundesamt für Naturschutz) 352.
177. Nentwig W, Kühnel E, Bacher S (2010) A generic impact-scoring system applied to alien mammals in Europe: Contributed paper. Conservation Biology 24:302–311 DOI: 10.1111/j.1523-1739.2009.01289.x.
178. Nentwig W, Bacher S, Pyšek P, Vilà M, Kumschick S (2016) The generic impact scoring system (GISS): a standardized tool to quantify the impacts of alien species. Environmental Monitoring and Assessment 188(5), 315.
179. Neubert MG and Caswell H (2000) Demography and dispersal: calculation and sensitivity analysis of invasion speed for structured populations. Ecology, 81: 1613- 1628.

180. Occhipinti-Ambrogi A, Savini D (2003) Biological invasions as a component of global change in stressed marine ecosystems. Marine pollution bulletin, 46(5), 542-551.
181. Occhipinti-Ambrogi A, Galil BS (2004) A uniform terminology on bioinvasions: a chimera or an operative tool? Marine pollution bulletin, 49(9-10), 688-694.
182. Ojaveer H and Kotta J (2015) Ecosystem impacts of the widespread non-indigenous species in the Baltic Sea: literature survey evidences major limitations in knowledge. Hydrobiologia, *750*(1), 171-185.
183. Ojaveer H, Galil BS, Lehtiniemi M, Christoffersen M, Clink S, Florin AB, Gruszka P, Puntila R, Behrens J (2015) Twenty-five years of invasion: management of the round goby Neogobius melanostomus in the Baltic Sea. Management of Biological Invasions, 6(4), 329-339.
184. Ojaveer H, Olenin S, Narščius A, Florin AB, Ezhova E, Gollasch S, Jensen KR, Lehtiniemi M, Minchin D, Normant-Saremba M, Strāke S (2016) Dynamics of biological invasions and pathways over time: a case study of a temperate coastal sea. Biological Invasions.
185. Ojaveer H, Galil BS, Carlton JT, Alleway H, Goulletquer P, Lehtiniemi M et al. (2018) Historical baselines in marine bioinvasions: Implications for policy and management. PloS one, 13(8), e0202383.
186. Olenina I, Wasmund N, Hajdu S, Jurgensone I, Gromisz S, Kownacka J, Olenin S (2010) Assessing impacts of invasive phytoplankton: the Baltic Sea case. Marine Pollution Bulletin, 60(10):1691-1700
187. Olenin S, Leppakoski E, Gollasch S, Gruzska P, Skora K, Hoppe K, Ojaveer H, Orlova M (2002) Recently introduced non-indigenous species. HELCOM. Baltic Sea Environment Proceedings. 173-175pp.
188. Olenin S, Minchin D, Daunys D (2007) Assessment of biopollution in aquatic ecosystems. Marine Pollution Bulletin, 55:379–394 DOI: 10.1016/j.marpolbul.2007.01.010.
189. Olenin S, Alemany F, Cardoso AC, Gollasch S, Goulletquer P, Lehtiniemi M. et al. (2010) Marine Strategy Framework Directive-Task Group 2 Report. Frontiers in Marine Science|www. Non-indigenous Species, Vol.44. EUR24342EN. Luxembourg: Office for Official Publications of the European Communities.
190. Olenin S, Elliott M, Bysveen I, Culverhouse PF, Daunys D, Dubelaar GB, et al. (2011) Recommendations on methods for the detection and control of biological pollution in marine coastal waters. Marine Pollution Bulletin 62,2598–2604. doi:10.1016/j.marpolbul.2011.08.011
191. Olenin S and Minchin D (2011) Biological introductions to the systems: macroorganisms, in Treatise on Estuarine and Coastal Science, Vol. 8, (eds) Wolanski E. and McLusky D.S. (Amsterdam: Elsevier), 149-183.

192. Olenin S, Narščius A, Minchin D, Galil B, Gollasch S, Marchini A et al. (2013) AquaNIS: a new generation information system on aquatic non-indigenous and cryptogenic species. Non-indigenous species in the North-East Atlantic, 48.

193. Olenin S, Narščius A, Minchin D, David M, Galil B, Gollasch S, Zaiko A (2014) Making non-indigenous species information systems practical for management and useful for research: an aquatic perspective. Biological Conservation, 173, 98-107.

194. Olenin S, Narščius A, Gollasch S, Lehtiniemi M, Marchini A, Minchin D, Srėbalienė G (2016) New arrivals: an indicator for non-indigenous species introductions at different geographical scales. Frontiers in Marine Science. *doi:10.3389/fmars.2016.00208.*

195. Olenin S, Ojaveer H, Minchin D, Boelens R (2016) Assessing exemptions under the ballast water management convention: preclude the Trojan horse. Marine Pollution Bulletin, 103(1), 84-92.

196. Olenin S (2017) The study of biological invasions in marine ecosystems during the period of shifts in research paradigms. Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki, 159(3), 510-520.

197. Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics, 37, 637-669.

198. Palialexis A, Tornero V, Barbone E, Gonzalez D, Hanke G, Cardoso AC et al. (2014) In-depth assessment of the EU member states' submissions for the Marine Strategy Framework Directive under articles 8, 9 and 10. JRC Scientific and Technical Reports, JRC, 88072.

199. Pheloung PC, Williams PA, Halloy SR (1999) A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57(4), 239-251.

200. Polunina JJ (2005) Populations of Two Predatory Cladocerans in the Vistula Lagoon – the Native *Leptodora kindtii* and the Non-Indigenous Cercopagis pengoi. Oceanological and Hydrobiological Studies, 34 (1): 249-260 pp.

201. Rabitsch W, Genovesi P, Scalera R, Biała K, Josefsson M, Essl F (2016) Developing and testing alien species indicators for Europe. Journal for Nature Conservation, 29, 89-96.

202. Raupach MJ, Amann R, Wheeler QD, Roos C (2016) The application of "-omics" technologies for the classification and identification of animals. Organisms Diversity & Evolution, 16, 1-12. doi:10.1007/s13127-015-0234-6

203. Reise K, Gollasch S, Wolff WJ (1998) Introduced marine species of the North Sea coasts. Helgoländer Meeresuntersuchungen, 52(3), 219.

204. Reise K, Olenin S, Thieltges DW (2006) Are aliens threatening European aquatic coastal ecosystems? Helgoland Marine Research, 60(2), 77.

205. Reusch TBH, Bolte S, Sparwel M, Moss AG, Javidpour J (2010) Microsatellites reveal origin and genetic diversity of Eurasian invasions by one of the

world's most notorious marine invader, *Mnemiopsis leidyi* (Ctenophora). Molecular Ecology, 19, 2690-2699. doi:10.1111/j.1365-294X.2010. 04701.x

206. Richardson MJ, Whoriskey FG, Roy LH (1995) Turbidity generation and biological impacts of an exotic fish Carassius auratus, introduced into shallow seasonally anoxic ponds. Journal of Fish Biology 47, 576-585 pp.
207. Roy, HE, Peyton J, Aldridge DC, Bantock T, Blackburn TM, Britton R. et al. (2014) Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Global Change Biology,* 20, 3859-3871. doi: 10.1111/gcb.12603
208. Roy HE, Rabitsch W, Scalera R, Stewart A, Gallardo B, Genovesi P. et al. (2017) Developing a framework of minimum standards for the risk assessment of alien species. Journal of Applied Ecology 55, 526-538. DOI: 10.1111/1365-2664.13025.
209. Rudinskaya LV and Gusev AA (2012) Invasion of the North American wedge clam *Rangia cuneata* (G.B. Sowerby I, 1831) (Bivalvia: Mactridae) in the Vistula Lagoon of the Baltic Sea. Russ. J. Biol. Invasions, 3 (3), 220—229, (in Russian).
210. Ruhi A, Catford JA, Cross WF, Escoriza D, Olden JD (2019) Understanding the nexus between hydrological alteration and biological invasions. In Multiple Stressors in River Ecosystems (pp. 45-64). Elsevier.
211. Rius M, Turon X, Bernardi G, Volckaert FA, Viard F (2015) Marine invasion genetics: from spatio-temporal patterns to evolutionary outcomes. Biological Invasions, 17, 869-885. doi:10.1007/s10530-014-0792-0
212. Sandvik H, Sæther BE, Holmern T, Tufto J, Engen S, Roy HE (2013) Generic ecological impact assessments of alien species in Norway: A semi-quantitative set of criteria. Biodiversity and Conservation, 22, 37-62. DOI: 10.1007/s10531-012-0394-z.
213. Shigesada N and Kawasaki K (1997) Biological invasions: theory and practice. Oxford Series in Ecology and Evolution. Oxford University Press, UK.
214. Simard N, Pelletier-Rousseau M, Clarke Murray C, McKindsey CW, Therriault TW, Lacoursière-Roussel A, Bernier R, Sephton D, Drolet D, Locke A, Martin JL, Drake DAR, McKenzie CH (2017) National Risk Assessment of Recreational Boating as a Vector for Marine Non-indigenous Species. DFO Canadian Science Advisory Secretariat Research Document 2017/006, vi + 95
215. Simkanin C, Davidson I, Falkner M, Sytsma M, Ruiz G (2009) Intra-coastal ballast water flux and the potential for secondary spread of non-native species on the US West Coast. Marine Pollution Bulletin, 58(3), 366-374.
216. Skora KE, Rzeznik J (2001) Observations on diet composition of Neogobius melanostomus Pallas 1811 (Gobiidae, Pisces) in the Gulf of Gdansk (Baltic Sea). Journal of Great Lakes Research, 27(3), 290-299.
217. Strong DR and Ayres DR (2013) Ecological and evolutionary misadventures of Spartina. Annual Review of Ecology, Evolution, and Systematics, 44, 389-410.

218. Schofield EK (1973) Galapagos flora: the threat of introduced plants. Biological Conservation, 5(1), 48-51.
219. Schofield PJ, Brown ME, Fuller PL (2006) Salinity tolerance of goldfish Carassius auratus L., a non-native fish in the United States. Florida Scientist, 69(4), 258.
220. Schlaepfer MA, Sax DF, Olden JD (2011) The potential conservation value of non-native species. Conservation Biology, 25(3), 428-437.
221. Sing LC and Tan KS (2018) Challenges in Managing Marine Bio-invasions via Shipping in Singapore. ASEAN Journal on Science and Technology for Development, 35(1-2), 125-132.
222. Solovjova S (2014) Baltijos jūros Lietuvos priekrantėje buvo rasta nauja moliuskų rūšis *Rangia cuneata* (G.B.Sowerby I, 1831) (Bivalvia: Mactridae) http://gamta.lt/cms/index?rubricId=d42d35cd-63cd-4800-9cfd-86ef9f305dac (2016-02-21)
223. Solovjova S, Samuilovienė A, Srėbalienė G, Minchin D and Olenin S (2019) Limited success of the non-indigenous bivalve clam *Rangia cuneata* in the Lithuanian coastal waters of the Baltic Sea and the Curonian Lagoon. Oceanologia, 61: 341-349.
224. Sundberg K and Kennedy VS (1993) Larval settlement of the Atlantic rangia, Rangia cuneata (Bivalvia: Mactridae). *Estuaries*, *16*(2), 223.
225. Snoeijs-Leijonmalm P, Schubert H, Radziejewska T. (Eds.) (2017) Biological oceanography of the Baltic Sea. Springer Science & Business Media.
226. Thomsen MS, Stæhr PA, Nejrup L, Schiel DR (2013) Effects of the invasive macroalgae Gracilaria vermiculophylla on two co-occurring foundation species and associated invertebrates. Aquatic Invasions, 8(2).
227. Tollington S, Turbe A, Rabitsch W, Groombridge JJ, Scalera R, Essl F, Shwartz A (2017) Making the EU legislation on invasive species a conservation success. Conservation Letters 10(1), 112-120.
228. Turbé A, Strubbe D, Mori E, Carrete M, Chiron F, Clergeau P et al. (2017) Assessing the assessments: evaluation of four impact assessment protocols for invasive alien species. Diversity and Distributions, 23(3), 297-307.
229. Uusitalo L, Blanchet H, Andersen JH, Beauchard O, Berg T, Bianchelli S, Cantafaro A, Carstensen J, Carugati L, Cochrane S, Danovaro R, Heiskanen A, Karvinen V, Moncheva S, Murray C, Neto J. M, Nygård H, Pantazi M, Papadopoulou N, Simboura N, Srėbalienė G, Uyarra MC, Borja A (2016) Indicator-Based Assessment of Marine Biological Diversity–Lessons from 10 Case Studies across the European Seas. Frontiers in Marine Science. *3:159. doi: 10.3389/fmars.2016.00159*.
230. UK TAG (2004) Guidance on typology for coastal & transitional waters of the UK and Republic of Ireland, UK TAG.

231. Václavík T and Meentemeyer RK (2012) Equilibrium or not? Modelling potential distribution of invasive species in different stages of invasion. Diversity and Distributions, 18(1), 73-83.
232. Vallet C, Dauvin JC, Hamon D, Dupuy C (2001) Effect of introduced common slipper shell on the suprabenthic biodiversity of the subtidal communities in the bay of Saint-Brieuc. Conservation Biology. Vol.15, No.6. 1686-1690.
233. Van Hoey G, Borja A, Birchenough S, Buhl-Mortensen L, Degraer S, Fleischer D et al. (2010) The use of benthic indicators in Europe: from the Water Framework Directive to the Marine Strategy Framework Directive. Marine Pollution Bulletin, 60(12), 2187-2196.
234. van Klinken R, Murray JV, Smith C (2015) Process-based Pest Risk Mapping using Bayesian Networks and GIS. Pest Risk Modelling and Mapping for Invasive Alien Species. CAB International, pp 171-188
235. Verbrugge LNH, Van der Velde G, Hendriks AJ, Verreycken H, Leuven RSEW (2012) Risk classifications of aquatic non-native species: application of contemporary European assessment protocols in different biogeographical settings. Aquatic Invasions 7, 49–58.
236. Verna DE, Harris BP, Holzer KK, Minton MS (2016) Ballast-borne marine invasive species: exploring the risk to coastal Alaska, USA. Management of Biological Invasions 7, 199–211, https://doi.org/10.3391/mbi.2016.7.2.08
237. Viard F, David P, Darling J (2016) Marine invasions enter the genomic era: three lessons from the past, and the way forward. Current Zoology, 62 (6), 629–642.
238. Vilà M and Hulme PE (2017) Non-native Species, Ecosystem Services, and Human Well-Being. In: Vilà M., Hulme P. (eds) Impact of Biological Invasions on Ecosystem Services. Invading Nature - Springer Series in Invasion Ecology, vol 12. Springer, Berlin.
239. Veit RR and Lewis MA (1996) Dispersal, population growth, and the Allee effect: dynamics of the house finch invasion of eastern North America. The American Naturalist, *148*(2), 255-274.
240. Verween A, Kerckhof F, Vincx M, Degraer S (2006) First European record of the invasive brackish water clam *Rangia cuneata* (G.B. Sowerby I, 1831) (Mollusca: Bivalvia) Aquatic Invasions, 1 (4), 198-203
241. Wakida-Kusunoke AT and MacKenzie CL (2004) Rangia and Marsh clams, *Rangia cuneata, R. flexuosa* and *Polymesoda caroliniana*, in Eastern Mexico: Distribution, biology and ecology, and historical fisheries. Marine Fisheries Review 66 (3), 13-20
242. Warzocha J, Drgas A (2013) The alien gulf wedge clam (*Rangia cuneata* G. B. Sowerby I, 1831) (Mollusca: Bivalia: Mactridae) in the Polish part of the Vistula Lagoon (SE. Baltic) Folia Malacologica 21, 291-292.

243. Warzocha J, Szymanek L, Witalis B, Wodzinowski T (2016) The first report on the establishment and spread of the alien clam *Rangia cuneata* (Mactridae) in the Polish part of the Vistula Lagoon (southern Baltic). Oceanologia, *58*(1), 54-58.
244. Webber B, Scott J (2012) Rapid global change: Implications for defining natives and aliens. Global Ecology and Biogeography 21, 305-311.
245. Werschkun B, Banerji S, Basurko OC, David M, Fuhr F, Gollasch S et al. (2014) Emerging risks from ballast water treatment: The run-up to the International Ballast Water Management Convention. Chemosphere, 112, 256-266.
246. Wiese L, Niehus O, Faass B, Wiese V (2016) Ein weiteres Vorkommen von Rangia cuneata in Deutschland (Bivalvia: Mac-tridae). Schr. Malakozool, 29, 53-60, Cismar.
247. Williamson MH and Brown KC (1986) The analysis and modelling of British invasions. Philosophical Transactions of the Royal Society of London. B, Biological Sciences, 314(1167), 505-522.
248. Williamson M (1999) Invasions. Ecography, 22(1), 5-12.
249. Wilson JR, Gaertner M, Richardson DM, Van Wilgen BW (2017) Contributions to the national status report on biological invasions in South Africa. Bothalia-African Biodiversity and Conservation, 47(2), 1-8.
250. Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, et al. (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science.* 314, 787-790. doi:10.1126/science.1132294
251. Wu H, Chen C, Wang Q, Lin J, Xue J (2017) The biological content of ballast water in China: a review. Aquaculture and Fisheries, 2(6), 241-246.
252. Zaiko A, Lehtiniemi M, Narščius A, Olenin S (2011) Assessment of bioinvasion impacts on a regional scale: a comparative approach. Biological Invasions, DOI 10.1007/s10530-010-9928-z
253. Zaiko A, Martinez JL, Ardura A, Clusa L, Borrell YJ, Samuiloviene A et al. (2015) Detecting nuisance species using NGST: methodology shortcomings and possible application in ballast water monitoring. Marine Environmental Research. 112, 64-72.
254. Vander Zanden MJ and Olden JD (2008) A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences, 65(7), 1512-1522.
255. Zimmermann NE, Edwards JrTC, Graham CH, Pearman PB, Svenning JC (2010) New trends in species distribution modelling. Ecography, 33(6), 985-989.

8

Santrauka

ĮVADAS

Temos aktualumas

Antropogeninio organizmų judėjimo už natūralaus arealo ribų tyrimai buvo pradėti daugiau nei prieš šešis dešimtmečius, kai Čarlzas Eltonas (2000) apibendrino žinias apie sausumos ir vandens rūšių plitimą savo įkvepiančioje knygoje „Gyvūnų ir augalų invazijų ekologija“ (1958). Nuo to laiko invazijų biologija tapo daugiadiscipline sritimi, sujungiančia fundamentaliuosius (pvz., biogeografiją, ekofiziologiją, aplinkos genetiką) ir taikomuosius (pvz., aplinkos kokybės vertinimus, aplinkos teisę, informacines technologijas) tyrimų aspektus (Olenin ir kt., 2017).

Invazijų biologijos mokslas sulaukia vis didesnio dėmesio ne tik iš akademinės bendruomenės (Cassey ir kt. 2018; Cardeccia ir kt., 2018; Ruhi ir kt., 2019; Jarić ir kt., 2019), bet ir iš politikų bei įvairių valstybinių ir privačių institucijų, pvz., dėstytojų, vietos bendruomenių, valstybinių įstaigų bei nevyriausybinių organizacijų (Wilson ir kt., 2017; Mazaris ir Katsanevakis 2018; Barney ir kt., 2019). Susidomėjimas didėja dėl to, kad kai kurios svetimkraštės rūšys (SR) geba plisti greitai, jų skaičius auga, o tai gali sukelti problemų žmonių sveikatai, ekonomikai ir vietinei aplinkai. Organizmų grupė, kuri paplito, plinta ar gali plisti į kitus regionus bei daro neigiamą poveikį biologinei įvairovei, socialinėms ir ekonominėms vertybėms ir (arba) žmonių sveikatai, vadinama svetimkraštėmis invazinėmis rūšimis (SIR) (Born ir kt., 2005; Molnar ir kt., 2008; Olenin ir kt., 2010; Bacher ir kt., 2018).

Vienas iš pagrindinių aplinkos apsaugos politikos dokumentų tikslų yra saugoti biologinę įvairovę, kuri yra laikoma sveikos ekosistemos kertiniu akmeniu (pvz., Worm ir kt., 2006; Uusitalo ir kt., 2016). Aplinkos apsaugos dokumentai gali būti taikomi pasauliniu (Biologinės įvairovės konvencija (BĮK 1992), Europos (pvz., Jūrų strategijos pagrindų direktyva (JSPD 2008); Invazinių svetimų rūšių reglamentas (ES 2014)) ir regioniniu (pvz., Baltijos jūros veiksmų planas (HELCOM 2007)) mastu. Kai kurie iš šių dokumentų susiję su konkrečiais SR plitimo keliais, pvz., svetimų ir nevietinių rūšių panaudojimo akvakultūroje ES reglamentas (ES 2007) ar laivų balastinio vandens ir nuosėdų valdymo ir kontrolės tarptautinė konvencija (TJO 2007). Pastarųjų dokumentų tikslas yra užkirsti kelią nepageidaujamam SR plitimui, vis dėlto daugelio dokumentų priemonių efektyvumas dar nėra įvertintas, kadangi daugumos ankstesniųjų dokumentų tikslai buvo deklaratyvūs (pvz., 1992 m. BĮK), o konkrečių teisiškai įpareigojančių aktų galiojimas yra trumpas, (pvz., 2017 m. Balastinio vandens konvencija ar 2014 m. Invazinių svetimų rūšių introdukcijos ir plitimo prevencijos ir valdymo reglamentas), todėl nėra pakankamas įvertinti ilgalaikį poveikį.

Siekiant vykdyti biologinių invazijų valdymą, tapo būtina parengti standartizuotus aplinkos būklės vertinimo metodus, kurie atitiktų aplinkos apsaugos politikos reikalavimus (Dana ir kt., 2014; Borja ir kt., 2017; Dickey ir kt., 2018). Atsiradus pirmosioms poveikio vertinimo metodikoms (Olenin ir kt., 2007; Molnar ir kt., 2008), susiformavo nauja taikomosios invazijų biologijos sritis, kurios tikslas sukurti objektyvų biologinių invazijų poveikio ir rizikos vertinimo metodiką (pvz., Copp 2009; Nentwig ir kt., 2010; Essl ir kt., 2011). Nors biologinių invazijų poveikio ir rizikos vertinimo sistemų ir metodikų skaičius didėja, kur daugiausia dėmesio skiriama poveikiui aplinkai, žmonių sveikatai, ekonomikai ir socialinei bei kultūrinei aplinkai, tačiau nėra vieningos nuomonės dėl tokių priemonių pasirinkimo jų praktiniam ar mokslinių tyrimų naudojimui (Mazza ir kt., 2014; Roy ir kt., 2017; González-Moreno ir kt., 2019).

Šiame tyrime analizuojami teisės aktų reikalavimai siekiant parengti biologinių invazijų poveikio ir rizikos vertinimo metodų tinkamumo vertinimo kriterijus. Šie kriterijai taikomi anksčiau minėtų metodų lyginamajai analizei atlikti. Kitas šio tyrimo aspektas yra sukurti aplinkos apsaugos politikos priemonių, kuriomis siekiama užkirsti kelią biologinių invazijų plitimui, efektyvumo vertinimo metodą. Šis metodas remiasi informacinės sistemos platforma, kuri sukurta pagal ES finansuojamą VECTORS projektą (Narščius ir kt., 2012; Olenin ir kt., 2014) šiuo metu ir vystoma Klaipėdos universiteto Jūrų tyrimų instituto. Taigi šis tiriamasis darbas gali būti priskiriamas taikomiesiems biologinių invazijų moksliniams tyrimams, kuriais siekiama sukurti biologinių invazijų praktinio valdymo būdus.

Tyrimo tikslas ir pagrindiniai uždaviniai

Šio tyrimo tikslas – parengti kriterijus biologinių invazijų poveikio ir rizikos vertinimo metodams įvertinti bei atlikti aplinkos apsaugos politikos dokumentų, skirtų biologinių invazijų prevencijai, efektyvumo įvertinimą.

Pagrindiniai uždaviniai:

1. palyginti ES invazinių svetimų rūšių (2018, Nr. 968/2018) rizikos įvertinimo reglamentą ir Tarptautinės jūrų organizacijos (2007 m.) rizikos vertinimo gaires pagal Reglamentą A-4, ir parengti kriterijų vertinimo schemą biologinių invazijų poveikio ir rizikos vertinimo metodams įvertinti;
2. atlikti lyginamąją jūrų biologinių invazijų poveikio ir rizikos vertinimo metodų analizę, taikant parengtą vertinimo kriterijų schemą;
3. sukurti ir taikyti indeksą *„nNIS“* vertinant naujų rūšių plitimo įvykius į Baltijos jūros regioną 2000–2009 ir 2010–2018 laikotarpiais;
4. nustatyti nevietinių rūšių invazyvumo potencialą, taikant „vidutinio plitimo greičio“ metodą, siekiant atskirti natūralius ir antropogeninius plitimo būdus.

Darbo naujumas

Šiame tyrime buvo pritaikytas naujasis indeksas „*nNIS*“ siekiant pritaikyti „vidutinio plitimo greičio“ metodą ir nustatyti invazinių rūšių būklę Baltijos jūroje pastaraisiais dešimtmečiais. Tai buvo pirmasis bandymas pateikti tipinių nevietinių rūšių, patenkančių į Baltijos jūrą, profilį atsižvelgiant į jų pagrindinius atplitimo kelius, poveikį aplinkai ir invazijos pasekmes. Pirmą kartą buvo palygintos ES invazinių svetimų rūšių introdukcijos ir plitimo prevencijos ir valdymo reglamentas (2014) ir Tarptautinės jūrų organizacijos laivų balastinio vandens ir nuosėdų valdymo ir kontrolės konvencija (2007) siekiant nustatyti bendrus rizikos ir poveikio vertinimo metodų reikalavimus ir kriterijus. Teisiniais dokumentais pagrįstas tinkamiausių kriterijų išskyrimas sukuria tinkamas gaires rizikos ir poveikio vertinimo metodų struktūrai ir tikslams.

Rezultatų mokslinė ir praktinė reikšmė

Šio darbo rezultatai papildė mokslines žinias apie rizikos ir poveikio vertinimo metodų taikymo modelius. Lyginamosios analizės rezultatai parodė biologinės invazijos poveikio ir rizikos vertinimo metodų privalumus ir trūkumus. Vertinimo sistema, parengta remiantis teisiniais jūrų politikos dokumentais, galėtų padėti parinkti tinkamiausius rizikos ir poveikio vertinimo metodus. Invazyvumo (vidutinio plitimo greičio) ir nNIS indeksas gali būti taikomi moksliniams, aplinkos stebėsenos programos ir jos valdymo tikslams pasiekti. Biologinių invazijų rizikos ir poveikio vertinimo metodų analizė atskleidė invazinių rūšių keliamo poveikio žmonių sveikatai ir ekonomikai mokslinių tyrimų poreikį.

Rezultatų aprobavimas

Šio darbo rezultatai buvo pristatyti 7 tarptautinėse ir 5 nacionalinėse konferencijose ir seminaruose:

Seminare „Iššūkiai susiję su biologiniu apaugimu ant laivų korpusų“. Roterdamas (Nyderlandai), 2019 m. balandis;

12-oje nacionalinėje konferencijoje “Jūros ir krantų tyrimai”. Klaipėda (Lietuva), 2019 m. gegužė;

11-oje nacionalinėje konferencijoje “Jūros ir krantų tyrimai”. Klaipėda (Lietuva), 2018 m. gegužė;

Kasmetinėje ICES mokslinėje konferencijoje. Fort Lauderdalas, Floridos valstija, (JAV), 2017 m. rugsėjis;

11-ame Baltijos jūros mokslų kongrese “Gyvenant palei gradientus: praeitis, dabartis, ateitis“. Rostokas, (Vokietija), 2017 m. birželis;

Seminare Norvegijos mokslo ir technologijų universitete, Biologinės įvairovės dinamikos centre, Trondheimas, Norvegija, 2016 m. lapkritis;

7-oje nacionalinėje konferencijoje “Jūros ir krantų tyrimai”. Klaipėda (Lietuva), 2014 m. gegužė;

6-oje nacionalinėje konferencijoje “Jūros ir krantų tyrimai”. Klaipėda(Lietuva), 2013 m. gegužė;

6-oje tarptautinėje studentų konferencijoje. Palanga, (Lietuva), 2012 m. spalis;

7-oje Europos biologinių invazijų konferencijoje NEOBIOTA, Pontevedra (Ispanija), 2012 m. rugsėjis;

IEEE/OES Baltijos tarptautiniame simposiume, Klaipėda, (Lietuva), 2012m. gegužė;

4-oje nacionalinėje konferencijoje “Jūros ir krantų tyrimai”. Palanga, (Lietuva), 2011 m. balandis.

Šios disertacijos rezultatai buvo paskelbti 5 mokslinėse publikacijose:

Srėbalienė G., Olenin S., Minchin D., Narščius A. (2019) A comparison of impact and risk assessment methods based on the IMO Guidelines and EU invasive alien species risk assessment frameworks. PeerJ, 7, e6965. https://doi.org/10.7717/peerj.6965

Solovjova S., Samuilovienė A., **Srėbalienė G.**, Minchin D., Olenin S. (2019) Limited success of the non-indigenous bivalve clam *Rangia cuneata* in the Lithuanian coastal waters of the Baltic Sea and the Curonian Lagoon. Oceanologia, 61: 341-349.

González-Moreno P., Lazzaro L., Vilà M., Preda C., Adriaens T., Bacher S., …., **Srėbalienė G** ir kt. (2019) Consistency of impact assessment protocols for non-native species. NeoBiota, 44: 1-25.

Uusitalo L., Blanchet H., Andersen JH., Beauchard O., **Srėbalienė G** ir kt. (2016) Indicator-Based Assessment of Marine Biological Diversity–Lessons from 10 Case Studies across the European Seas. Frontiers in Marine Science, 3:159. doi: 10.3389/fmars.2016.00159.

Olenin S., Narščius A., Gollasch S., Lehtiniemi M., Marchini A., Minchin D., **Srėbalienė G.** (2016) New arrivals: an indicator for non-indigenous species introductions at different geographical scales. Frontiers in Marine Science. 3:208. doi:10.3389/fmars.2016.00208.

Disertacijos struktūra

Disertaciją sudaro tokie skyriai: įvadas, literatūros apžvalga, medžiaga ir metodai, rezultatai, diskusija, išvados, literatūros sąrašas ir priedai. Disertacijos apimtis – 108 puslapiai. Disertacijoje panaudoti 249 literatūros šaltiniai. Disertacija parašyta anglų kalba su išplėstine santrauka lietuvių kalba. Joje yra 12 lentelių, 26 paveikslai ir 9 priedai.

Padėka

Labiausiai norėčiau padėkoti savo darbo vadovui profesoriui Sergej Olenin, Jūs buvote mano įkvėpėjas. Norėčiau padėkoti už rekomendacijas per visus šiuos metus ir už tai, jog leidote man augti kaip mokslininkei. Jūsų įkvėpimas, patarimai ir kritika buvo neįkainojami.

Taip pat norėčiau padėkoti dr. Dan Minchin ir dr. Anastasijai Zaiko, už patarimus ir paramą doktorantūros studijų pradžioje. Didžiausia padėka dr. Aleksui Narščiui už vertingą indėlį, padrąsinimą ir įkvepiančias, kartais labai linksmas diskusijas studijų laikotarpiu.

Labai ačiū dr. Hanno Sandvik už galimybę apsilankyti Norvegijos Mokslų ir Technologijos universitete, Biologinės įvairovės dinamikos centre už įgytas žinias, už „plitimo modelį“ ir šiltą sutikimą bei priėmimą Trondheime.

Esu dėkinga dr. Marijai Kataržytei, prof. M.R. Sopota už disertacijos apžvalgą ir vertingus patarimus, doktorantų paramą, pagalbą ir visas linksmybes kurias mes kartu praleidome konferencijų, kursų ir kelionių metu.

Ypatingas ačiū mano kolegoms ir Klaipėdos universiteto darbuotojams, Jūros tyrimų instituto ir Jūrų technologijos ir gamtos mokslų fakulteto kolegoms, ypač visiems doktorantams Tomai, Viktorijai, Sabinai, Gretai, Donatai, Donaldai, Migeliui, savo kambariokei Rasai ir kolegoms dr. Loretai Rimkienei-Kelpšaitei, Vitalijui Kondrat.

Ypatinga padėką skiriu dr. Zitai Gasiūnaitei ir dr. Viktorijai Vaitkevičienei už teigiamą požiūrį ir draugišką darbo atmosferą.

Taip pat norėčiau padėkoti mylimam vyrui Mindaugui Srėbaliui už supratimą, palaikymą, ramybę ir optimizmą. Be tavo pagalbos tai būtų buvę sunku įgyvendinti, ačiū tau. Ir ačiū sakau Gaivilei ir Šarūnui – už tai, kad esate, palaikote ir įnešate džiaugsmo į mano gyvenimą.

Nuoširdų Ačiū sakau savo tėvams, seserims Solvitai ir Danguolei bei anytai Reginai už pagalbą „prižiūrint vaikus“ ir visokeriopą palaikymą. Labai ačiū draugėms Linai, Agnei, Kornelijai, Laurai. Labai dėkoju draugams iš laisvalaikio ir užimtumo klubo „Liūnas“, be mūsų bendrų užsiėmimų mano gyvenimas būtų liūdnesnis.

Šiam darbui finansinę paramą suteikė DEVOTES (2012-2016), VECTORS (2011-2015) projektai finansuojami pagal ES Septintąją bendrąją programą, ir Interreg Baltic Sea Region programos finansuojamas COMPLETE (2017-2020) projektas.

TYRIMŲ MEDŽIAGA IR METODAI

Rizikos ir poveikio vertinimo metodų palyginimas

Vertinimo kriterijų nustatymas remiantis aplinkos pasaugos politikos dokumentais

Tyrimo metu siekiant parengti gaires standartizuotai rizikos ir poveikio vertinimo sistemai buvo lyginami ES invazinių svetimų rūšių introdukcijos ir plitimo prevencijos ir valdymo reglamento (2014) (nuostatos dėl rizikos vertinimo, susijusio su invazinėmis svetimomis rūšimis, papildančios Europos Parlamento ir Tarybos Reglamento Nr. 1143/2014) (toliau Reglamentas) ir Tarptautinės jūrų organizacijos laivų balastinio vandens ir nuosėdų valdymo ir kontrolės konvencijos (2007) nuostatai (7 pav.). Rizikos vertinimo metodikos buvo peržiūrėtos atsižvelgiant į šiuos aspektus: i) pagrindinius vertinimo proceso principus, ii) vertinimo kategorijas ir iii) biologinių invazijų poveikio tipus.

Tarptautinės jūrų organizacijos (toliau TJO) konvencijos gairėse apibrėžiami pagrindiniai principai – veiksmingumas, skaidrumas, nuoseklumas, visapusiškumas, rizikos valdymas, prevencinis, moksliškai pagrįstas, nuolatinis atnaujinimas, į kuriuos turėtų būti atsižvelgta vykdant rizikos vertinimą. Tuo tarpu ES Reglamento (2014) 2018 m. papildomose nuostatose minimi tokie patys rizikos vertinimo principai, tačiau jie nėra aiškiai identifikuoti ir aprašyti, kaip tai atlikta TJO gairėse. Todėl šiame darbe vertinimas grindžiamas aštuoniais principais, išvardytais TJO konvencijos gairėse. Minėtame dokumente apibrėžiami trys rizikos vertinimo aspektai: aplinkos sąlygų panašumas (i), biogeografinis vertinimas (ii) ir konkrečios svetimkraštės rūšies atvejo vertinimas (iii). Šie rizikos vertinimo aspektai iš dalies atsispindi aštuoniuose Reglamento (ES Nr. 1143/2014) 5 straipsnio 1 dalies *a–h* punktuose. Remdamiesi šių aplinkos apsaugos politikos dokumentų lyginamosios analizės rezultatais, į vertinimo procedūrą įtraukėme 29 vertinimo komponentus, kurie nurodyti ES invazinių svetimų rūšių introdukcijos ir plitimo prevencijos ir valdymo Reglamento 2018 m. nuostatose.

Vertinimo procedūra

Remiantis TJO gairių ir ES Reglamento palyginimu, į vertinimo procedūrą buvo įtraukti aštuoni pagrindiniai TJO gairių principai, dvidešimt devyni rizikos vertinimo komponentai nurodyti ES Reglamente ir keturi biologinių invazijų poveikio tipai, kurie minimi abiejuose analizuojamuose dokumentuose (7 pav.). Atlikus išsamią literatūros analizę, buvo įtrauktos papildomos poveikio kategorijos (Emerton ir Howard 2008; David ir Gollasch 2015; Olenin ir kt. 2016; Vilà ir Hulme 2017), kurios nebuvo paminėtos analizuojamuose dokumentuose. Iš viso buvo įtraukta 41 kategorija, kurios priskirtos vienam iš biologinių invazijų poveikio tipui: žmonių sveikata (6 kategorijos), ekonomika (11 kategorijų), aplinka (20 kategorijų), socialiniai ir kultūriniai aspektai (4 kategorijos) (1 lent.). Poveikio tipų ir kategorijų aprašymai pateikti 1 priede. Sukurta balų vertinimo sistema, kurios tikslas įvertinti atitiktį kiekvieno iš aštuonių pagrindinių principų (2 lent.). Rizikos vertinimo kategorijų ir poveikio tipų buvimas ar nebuvimas buvo vertinamas pagal pasirinkto požymio aprašymą. Bendras pasirinktų metodų įvertis buvo grindžiamas sukauptuoju balu ir išreiškiamas kaip atitikimo pasirinkto kriterijaus procentinė išraiška.

Biologinių invazijų poveikio ir rizikos vertinimo metodų atranka

Atliekant biologinių invazijų poveikio ir rizikos vertinimo metodų atranką, buvo panaudotas aktualiausių metodų sąrašas, kurį sudarė Roy ir kt (2017) pagal COST Action Alien Challenge TD1209 programą. Šios programos metu buvo atlikta literatūros apžvalga, identifikuojant invazinių rūšių rizikos vertinimo metodus, šiame darbe buvo atlikta papildoma literatūros šaltinių paieška ir ja remiantis buvo atrinkti papildomi rizikos ir poveikio vertinimo metodai.

Metodų atranka buvo atlikta atsižvelgiant į tris kriterijus: 1) metodika turi būti taikytina svetimkraštėms vandens rūšims, 2) poveikio vertinimo sistema įtraukia bent vieną iš šių poveikio vertinimo kategorijų – žmogaus sveikata, aplinkos apsauga, ekologija ekonomika, socialinis ir kultūrinis poveikis, 3) rizikos ir poveikiai yra vertinami taikant kokybinio arba kiekybinio vertinimo sistemas. Galutinei analizei buvo atrinkta penkiolika metodų, tinkamų mūsų analizei (3 lent.). Daugelis analizuotų metodų buvo sukurti laikotarpiu tarp 2007 ir 2016 m., kai kurie iš jų vis dar tobulinami ir nuolat atnaujinami. Rizikos ir poveikio metodų charakteristikos buvo vertinamos remiantis pagrindinėmis publikacijomis, kuriose aprašyti pastarieji metodai. Galutinei analizei buvo atrinkta ir įvertinta 15 rizikos ir poveikio vertinimo metodų, naudojant 78 kriterijus, kurie pagrįsti dviejų aplinkos apsaugos politikos dokumentų nuostatomis ir 40 literatūros šaltinių analize.

AquaNIS informacinė sistema ir nNIS indeksas

AquaNIS duomenų tipas

Ši tyrimo dalis pagrįsta duomenimis, sukauptais informacinėje duomenų sistemoje – AquaNIS, kurioje kaupiami duomenys apie svetimkraštes ir kriptogenines rūšis (Olenin ir kt., 2014; AquaNIS 2019). Visos šalys yra priskirtos tam tikrai Didžiųjų jūrų ekosistemų (toliau DJE) sistemos daliai arba DJE subregionui.

Pagrindiniai duomenų įrašai AquaNIS sistemoje yra „atplitimo įvykis“ (ang. *introduction event*), apibūdinant svetimkraštės rūšies atplitimo regioną (ang. *recipient region*), susiejant jį su šalies arba šalies regiono, arba keliais regionais pagal DJE arba DJE su subregionų klasifikacija. Įvedant informaciją apie atplitimo įvykį suvedama informacija apie introdukcijos metus, kada buvo rūšis pastebėta, taip pat inrodukcijos keliai nurodant skirtingus patikimumo lygius. Be to, AquaNIS kaupiama informacija apie rūšių biologines savybes, toleranciją aplinkos sąlygoms, genetinę informaciją rūšiai identifikuoti, buveines ir kitą informaciją, susijusią su introdukcijos įvykiu. Be to, informacinėje sistemoje įdiegta struktūrinė „paieškos“ funkcija analizuoti pagal pasirinktus paieškos kriterijus (Olenin ir kt., 2014).

nNIS indekso taikymas

nNIS yra indeksas, kuris rodo naujų SIR skaičių vertinamajame vienete. Šiame tyrime vertinamuoju vienetu yra laikomas introdukcijos regionas (angl. *recipient region*), AquaNIS duomenų bazėje, suprantamas kaip šalis, šalies regionas, vienas ar keletas DJE regionų. Baltijos jūros atveju, skaičiuojama 10 introdukcijos regionų: aštuonios Baltijos jūros šalys ir du atskiri Rusijos Federacijos regionai, Sankt Peterburgo regionas Suomijos įlankoje (RU_S) ir Kaliningrado sritis Pietryčių Baltijos jūros dalyje (RU_K). Pirminis įvertinimas yra pradinis visų SR, esančių introdukcijos regione, inventorizacijos atlikimas. Šio tyrimo metu buvo surinkti duomenys apie naujus SR atplitimo įvykius į Baltijos jūrą 2000–2018 laikotarpiu, šį periodą vertinome juos padalinę į du atitinkamus laikotarpius 2000–2009 ir 2010–2018.

Šis indeksas padeda įvertinti prevencinių priemonių, skirtų svetimkraščių rūšių patekimo į naujas ekosistemas rizikos mažinimui. Pagal siūlomą metodiką, *nNIS* rodo naujai užregistruotų SR skaičių vertinamoje teritorijoje analizuojamuoju periodu. Šis indeksas taip pat parodo, kokioje geografinėje skalėje rūšis nauja: 1) ar tik tam tikros šalies priekrantėje (pvz., aptikta Lietuvoje, tačiau ankščiau buvo jau paplitusi kitose Baltijos jūros šalyse); 2) nauja Baltijos jūroje; 3) nauja visame Baltijos ir kaimyninės Šiaurės jūrų regione (t .y. pirmąkart atplito į šį regioną).

Šiame tyrime analizuojami du introdukcijos atplitimo būdai: a) pirminis (pradinis) atplitimas (ang. *primary introduction*) – tai pirmasis SR atplitimo į konkretų vertinamąjį regioną atvejis, b) antrinis plitimas (angl. *secondary introduction*), tai tolesnis rūšies plitimas kitose, dažniausiai kaimyninėse šalyse. Pirminė introdukcija – tai SR atplitimas į vertinamą teritoriją; antrinė introdukcija – tai tolesnis rūšies plitimas iš pirminės introdukcijos regiono. Pirminės introdukcijos naujumo geografinis kontekstas (t.y. ar SR nauja šaliai, jūrai ar platesniam regionui) įvertinamas pagal AquaNIS informacinėje sistemoje sukauptus duomenis. Apskaičiuojamas *nNIS* indeksas ir pateikiamas SR sąrašas, jų atplitimo įvykių datos bei atplitimo vektorius (daugiau informacijos Olenin ir kt., 2016).

Aplinkos apsaugos politikos požiūriu svarbesnis yra pirminio atplitimo atvejis, kuomet atplintančioji SR yra nauja šalies (introdukcijos regiono) ar DJE ar DJE subregiono atžvilgiu. Baltijos jūros atveju, žemiausias pirminio atplitimo lygis (L1) yra vienas iš 10 introdukcijos regionų, kitas lygis (L2) yra visas DJE (Baltijos jūra), o aukščiausias lygis (L3) yra du kaimyniniai DJE (Baltijos jūra ir Šiaurės jūra). Taigi, *nNIS* L1 rodo, kiek naujų SR buvo užregistruota konkrečioje šalyje, *nNIS* L2 rodo, kiek iš jų buvo naujų Baltijos jūros regiono atžvilgiu, o *nNIS* L3 rodo, kad tiek Baltijos, tiek Šiaurės jūrose yra naujų SR.

Pasitelkus AquaNIS duomenų bazę *nNIS L1* vertės išgaunamos, naudojant paieškos funkciją. Visų čia pateiktų *nNIS* verčių skaičiavimai grindžiami duomenimis, kurie sukaupti AquaNIS duomenų bazėje iki balandžio 12 d., 2019 (AquaNIS 2019). Sistemoje esantiems duomenims apie introdukcijos įvykį, pirminio ir antrinio atplitimo kelią ar vektorių, introdukcijos įvykio laiką (metus) priskiriamas atitinkamas patikimumo lygmuo (4 lent.; 5 lent.,). BPL indekso vertės sukeltos į duomenų bazę AquaNIS (AquaNIS 2019) (Olenin ir kt. 2007). Metodika grindžiama svetimų rūšių gausos ir pasiskirstymo diapazono klasifikavimu ir jų poveikio vietinėms bendruomenėms, buveinėms ir ekosistemų funkcionavimui dydžiu, indekso (BPL) vertės matuojamos nuo „nėra poveikio“ (BPL = 0) iki „masinio poveikio“ (BPL = 4).

Invazyvumo potencialo matavimo metodas grindžiamas pusiau kiekybine ekologinio poveikio vertinimo schema (Sandvik ir kt. 2013). Svetimkraštės rūšies plitimas yra apibūdinamas kaip atskirų organizmų savarankiškas judėjimas, taip pat judėjimas veikiant gyvūnų, vandens, vėjo ar kitiems veiksniams, tokiems kaip antropogeninės kilmės transportui ar atskiriems introdukcijos (tiksliniams ir netiksliniams) įvykiams (Sandvik ir kt. 2013). Plitimo vertės yra modeliuojamos kaip vidutinis greitis v, naudojant visus rūšių aptikimus. Vidutinis plitimo greitis yra sumodeliuoti kaip faktinis arba numanomas invazijos fronto greitis v. Vertinant svetimkraščių rūšių invazyvumo potencialą taikomas MER (angl. *Mean Expansion Rate*) metodas, kuris nustato plitimo greitį (PG). Šis pusiau kiekybinis metodas remiasi poveikio vertinimo sistema GEIAA (Sandvik ir kt., 2013). Taikant MER metodą, rūšies invazyvumo potencialas skirstomas į keturis lygius pagal plitimo greitį: mažas (<0,3 km. per metus), nedidelis (≥0,3 km. per metus), vidutinis (≥ 10 km. per metus) ir aukštas (≥ 30 km. per metus). Skaičiuojant svetimkraštės rūšies PG buvo surinkti duomenys apie *R.cuneata* rūšies aptikimo vietas, tikslios jų koordinatės. Duomenų analizei buvo naudojamos rūšies aptikimo taškų koordinatės, istoriniai bei naujų tyrimų ir stebėsenos duomenys, kurie buvo atrinkti atlikus literatūros apžvalgą arba naudojant duomenų bazes, pavyzdžiui, AquaNIS, ICES. Gauti duomenys buvo suskirstyti į grupes pagal jų kilmę: tikslios koordinatės, koordinatės, nustatytos skaitmeninant žemėlapį, koordinatės, paremtos eksperto žiniomis, arba remiantis žodiniu vietos aprašymu (pvz., „rūšis buvo rasta šiaurinėje Kuršių marių dalyje"). Duomenys ir koordinatės pateikiami 8 priede.

REZULTATAI

Rezultatai pristatyti 4 skyriuose: *1) Vertinimo kriterijų atranka, remiantis aplinkos apsaugos teisiniais dokumentais, 2) Rizikos ir poveikio vertinimo metodų palyginimas, 3) Naujų SIR, atplitusių nuo 2000 m .į Baltijos jūrą, analizė 4) Svetimkraščių rūšių invazyvumo potencialo vertinimas*

Pirmame skyriuje pateikti rezultatai apie rizikos ir poveikio vertinimo metodų kokybę, taip pat palyginti du teisės aktų dokumentai ir sukurta vertinimo sistema (7 pav.). TJO gairėse apibrėžti trys rizikos vertinimo aspektai: aplinkos sąlygų panašumas (i), biogeografinis vertinimas (ii) ir konkrečios svetimkraštės rūšies atvejo vertinimas (iii). Visi šie požiūriai atsispindi kiekviename iš aštuonių straipsnių, kuriuose aprašomi rizikos vertinimo komponentai ES reglamente (5 straipsnio 1 dalies *a–h* punktai). Tačiau TJO gairės tiesiogiai neatitinka dviejų lygiaverčių ES reglamento straipsnių (5 straipsnio 1 dalies *g* ir *h* punktų) (3 lent.) ir tik iš dalies nurodo kitus šešis straipsnius. Be to, ES Reglamente trumpai aprašomi komponentai, į kuriuos reikia atsižvelgti atliekant rizikos ir poveikio vertinimą. Šiame tyrime įtraukėme visus 29 ES reglamento rizikos vertinimo komponentus į bendrą vertinimo procedūrą (3 lent.). Lyginamosios analizės rezultatai apie skirtumus ir panašumus, esančius tarp dviejų analizuojamų dokumentų, pateikti 7 lentelėje.

Antrame skyriuje pateikiami atrinktų rizikos ir poveikio vertinimo metodų palyginimo rezultatai. Šiame skyriuje buvo vertinama metodikų vertinimo procedūros kokybė pagal atrinktus kriterijus bei atitikimą komponentams ir principams, išreikštą procentais. Atitikties pagrindiniams principams vertinimo santrauka pateikta 8 lentelėje, o išsamūs vertinimo rezultatai pateikti 2 priede. Remiantis analize buvo nustatyta, kad visi atrinkti metodai atliekant rizikos vertinimą į vertinimo procedūrą įtraukia bendrą informaciją apie nevietines rūšis (9 lent.; 3 priedas). Dažniausiai rizikos ir poveikio vertinimo metoduose įtraukti rizikos vertinimo komponentai yra susiję su SR dauginimosi ir paplitimo būdu, plitimo kelių ir vektorių analize, invazijos proceso identifikacija (9 lent.). Rečiausiai įtraukiami poveikio tipai, susiję su ekonominės žalos atlygiu ir SR panaudojimo būdais, bei jų potenciali teigiama nauda. Poveikis žmonių sveikatai vertinamas 57% metodų, dažniausiai vertinamas „bendras poveikis žmogaus sveikatai", tuo tarpu trys metodai (GB NNRA, GISS, HARMONIA +), vertinant poveikį žmonių sveikatai, atsižvelgia į specifinį poveikį žmogaus sveikatai: poveikis per parazitus, patogenus, toksinius junginius, potencialią grėsmę per apsinuodijimus ir nuodingus organizmus. Šie rezultatai apibendrinti (10 lent.; 8 pav.) ir pateikta papildoma informacija (4 priedas). GISS metodas įtraukia 90% aplinkosauginių kategorijų, atitinkamai metodai TRAAIS (80 proc.) ir SBRA (75%) taip pat įtraukia svarbiausias aplinkosaugines kategorijas. 60 % metodų apėmė ekonominio poveikio kategoriją su bendrosiomis valdymo išlaidomis (60%) arba poveikiu akvakultūrai (47%), žuvininkystei (40%) arba melioracijai ir žalą navigacinėms sistemoms (40%). Metodai GABLIS, GISS ir SBRA vertinimo procese įtraukė daugiau nei pusę minėtų ekonominių kategorijų: atitinkamai 55, 64 ir 64%. Vertinant poveikį socialinei ir kultūrinei aplinkai buvo atsižvelgta į 53% metodų, dažniausiai pasitaikančios kategorijos yra poilsiui ir turizmui (53%). SBRA metodas atsižvelgė į 75% poveikio socialinėms-kultūrinėms vertybėms kategorijas. Bendras metodų vertinimas pagal pagrindinius principus, rizikos vertinimo komponentus ir poveikio kategorijas pateikiamas 9 pav., o metodų vertinimas pagal kriterijus pateikiamas 10 pav. Metodas, kuris atitiko didžiąją dalį atrinktų kriterijų ir principų, yra SBRA. Šis metodas atitiko pagrindinius principus, rizikos vertinimo komponentus, apėmė plačiausią poveikio kategorijų spektrą, sekantys metodai kurie taip pat atitiko iškeltus kriterijus buvo HARMONIA + ir AS-ISK. Kitas metodas, kuris iš esmės atitiko pagrindinius principus ir visus rizikos ir poveikio komponentus, buvo RABW, kuris sukurtas remiantis BVTK gairėmis. Vis dėlto ši metodika poveikio ir rizikos vertinimo procese įtraukia mažiausiai poveikio kategorijų lyginant su kitais vertinimo metodais. Daugiausiai poveikio kategorijų įtraukia GISS metodas, tačiau bendroji atitiktis su atrinktais rizikos vertinimo komponentais ir kriterijais yra palyginti nedidelė.

Trečiame skyriuje pateikiami naujų svetimkraščių rūšių, atplitusių nuo 2000 m. į Baltijos jūrą, analizė. Baltijos jūros regiono šalyse 2000–2018 laikotarpiu iš viso buvo užfiksuoti 149 atplitimo įvykiai, susiję su 75 svetimkraštėmis rūšimis, vertinat atskirais laikotarpiais I (2000–2009) užregistruotos 44 svetimkraštės rūšys, tuo tarpu II (2010–2018) periodu 31 svetimkraštė rūšis (5 priedas). Dviejų laikotarpių palyginimas parodė, kad yra skirtumų, atsižvelgiant į taksonominį rūšių pasiskirstymą. Baltijos jūros šalyse didžioji dalis užregistruotų SR priklauso šiems tipams: nariuotakojams (43%), žieduotosioms kirmėlėms (15%), chordiniams / stuburiniamas (10%), moliuskams (10%) ir rudadumbliams) (5%) (11 pav.).

Svetimkraščių rūšių biologinės savybės ir charakteristikos. Remiantis hipoteze, kad SR turinčios pelaginę vystymosi stadiją turi didesnį potencialo plisti balastinių vandenų dėka atlikta atplitusių rūšių biologinių savybių ir charakteristikų analizė. Šio tyrimo rezultatai parodė, kad iš 75 SR, kurios išplito Baltijos jūros regione, 63% rūšių (47 iš 75 SR) turi pelaginės lervos stadiją, tuo tarpu likusios rūšys, t.y. 37% (28) SR, vystymosi periodu neturi pelaginės stadijos (lervos, kiaušinėlių ir kt.). SR palyginimas pelaginės stadijos atžvilgiu, t.y. SR skaičius su pelagine stadija ir be pelaginės stadijos, tarp dviejų analizuojamų laikotarpių buvo nustatyti ryškūs skirtumai. Nustatyta, kad SR, turinčių pelaginę stadiją, skaičius sumažėjo nuo 30 iki 17. Pirmojo laikotarpio (2000–2009) rūšims su pelagine lervų stadija, kur atitinkamai nustatyta, 68% ir 32%, o 2010 m. vyko SR, turinčių pelaginę vystymosi stadiją, skaičiaus sumažėjimas (12 pav.). Analizė taip pat parodė, kad iš viso 16 SR plito 2000–2018 m. laikotarpiu, ir dauguma iš jų (13 iš 16) turi pelaginę vystymosi stadiją (*M. viridis, E. anonyx, H. anomala, H. americanus, P. macrodactylus, P. longirostris, P. elegans, R. harrisii, A. gueldenstaedtii, N. melanostomus, D. bugensis, M. leucophaeata, P. cordatum*), tuo tarpu 3 iš 16 svetimkraščių rūšių (*P. moldaviensis, G. tigrinus, D. villosus*) neturi pelaginės stadijos.

Svetimkraštės rūšies kilmės regionas. SR (tik pirminės introdukcijos) kilmės regiono analizės rezultatai parodė, kad pastaruosius 18 metų SR dominuojantis kilmės regionas yra Ponto–Kaspijos regionas (14 pav.). Šiam regionui priskiriamos rūšys, kurios galėjo atplisti iš Juodosios ar / ir Kaspijos jūros regiono, šis kilmės regionas nurodomas 33% visų atplitusių rūšių (25 iš 75 SR) į Baltijos jūrą. Antras vyraujantis kilmės regionas tai Šiaurės Vakarų Atlanto (24%), Šiaurės Vakarų Ramiojo vandenyno (19%) regionai. Kai kurių rūšių kilmė buvo nežinoma (11%) ir tuo atveju, kai kilmės regionas buvo kitoks (skiriasi nuo Ponto–Kaspijos, Šiaurės Vakarų Atlanto, Šiaurės Vakarų Ramiojo vandenyno regiono) jie buvo priskirti prie kategorijos „kiti regionai“ (5%).

Galimas poveikis aplinkai. Naudojant turimus duomenis apie BPL (biotaršos indeksą) vertes skirtingose Baltijos jūros dalyse, buvo išanalizuotos 75 SR poveikio vertės. Atliekant vertinimą šalyse / regionuose paaiškėjo, kad dokumentuotas ekologinis poveikis yra žinomas tik 27 iš 75 SR, registruotų Baltijos jūroje 2000–2018 m. laikotarpiu (15 pav.). Šešių SR silpno lygio (BPL = 1) poveikis aplinkai buvo apibrėžtas vienoje ar daugiau Baltijos jūros dalių, 13 SR poveikis buvo vidutiniškas (BPL = 2), 6 SR stiprus (BPL = 3), ir tik 2 SR poveikis buvo vertinami kaip masyvus (BPL = 4). Duomenys rodo, kad poveikio mastas gali būti įvairus, priklausomai nuo vertintos buveinės, poveikio lygis gali kisti nuo silpno (BPL = 1) iki masyvaus (BPL = 4). Rezultatai rodo, kad bendros biotaršos indekso vertės sumažėjo paskutiniu laikotarpiu – 2010–2018 m.. Tačiau, pažymėtina, kad didėja SR, kurių poveikio lygis nėra įvertintas, skaičius, pvz. 2000–2009 m. laikotarpiu tokių rūšių buvo 48%, tuo tarpu 2010–2018 m. – 68% (16 pav.).

Per pastaruosius devynerius metus 7 iš 10 šalių / šalių regionų „atplitimo įvykių“ padaugėjo, dvigubas padidėjimas buvo nustatytas Vokietijoje (24), šiek tiek mažesnis padidėjimas nustatytas Lenkijoje (13) ir Latvijoje (7) (13 pav.). Siūlomo *nNIS* indekso taikymo rezultatai parodė, kad šalys ir regionai, kaip turintys didžiausią pirminės introdukcijos potencialą, buvo užregistruoti dviem laikotarpiais – 2000–2009 ir 2010–2018.

Skirtumas tarp *nNIS* L1 ir L2 rodo atplitusių svetimkraščių rūšių skaičių, kurių atplitimo tipas priskiriamas prie yra antrinio plitimo t.y. atplito iš kaimyninių regionų į konkretaus regiono. Pavyzdžiui, vertinant šalį ar regioną pagal *nNIS* indeksą paaiškėjo, kad nors Vokietijoje buvo užregistruotos 24 SR, 2010–2018 m. laikotarpiu, t. y. *nNIS* L1_Vokietija = 24 (11 lent.; 5 priedas; 15 pav.). Tačiau iš 24 tik 14 rūšių į Baltijos jūrą pateko pirminės introdukcijos būdu (*nNIS* L2_Voktiejia = 14), o dvi rūšys iš jų (*H. solitaria* ir *E. carolleeae*) buvo naujos didesnio biogeografinio regiono lygmeniu, kuris apima Baltijos ir Šiaurės jūrą DJE (*nNIS* L3_Vokietija = 2). Lenkijoje užregistruota trylika naujų rūšių; keturios iš jų paplito Baltijos jūroje nuo 2010 m. ir viena SR buvo nauja Baltijos ir Šiaurės jūrų atžvilgiu. Pastaroji rūšis (*P. hammoniensis*) yra nauja L3 skalės atžvilgiu, t. y. SR yra nauja Baltijos ir Šiaurės jūros atžvilgiu. Lietuvoje pasirodė trys naujos SR, tačiau nė viena iš jų nebuvo nauja DJE regiono lygmeniu (*nNIS* L2_Lietuva = 0 arba *nNIS* L3_Lietuva = 0) (5 priedas).

Baltijos jūros DJE (L2) analizės metu 2010–2018 laikotarpiu buvo nustatyti du pagrindiniai plitimo keliai: „natūralus plitimas iš kaimyninių regionų“ (38%) ir „laivai“ (37%). Plitimas iš kaimyninių šalių ir laivyba iš Šiaurės jūros gali būti laikomi vieni didžiausių veiksnių, lemiančių SR paplitimą Baltijos jūroje. Kiti galimi keliai tai kanalai ir su akvakultūra susijusi ūkinė veikla. Dviejų laikotarpių palyginimas atskleidė, kad 2010–2018 m. laikotarpiu sumažėjo SR skaičius, kurių atplitimo kelias buvo laivai (39% ir 34%), taip pat sumažėjo SR skaičius kaimyninėse šalyse (44% ir 29%).

Ketvirtame skyriuje pateikiami svetimkraščių rūšių invazyvumo potencialo vertinimo rezultatai. Iš 75 SR, kurios atplito 2000–2018 m. laikotarpiu, buvo atrinktos 10, rūšių atranka buvo vykdoma pagal georeferencinių duomenų gausumą (6 priedas). Didžiausia plitimo vertė buvo nustatyta myzidei (*H. anomala*) 168 km per metus, mažiausia plitimo vertės nustatytos Australijos daugiašerei kirmėlei (*F. enigmaticus*) ir gauruotajai šoniplaukai (*D. villosus*) (21 pav.). 7 iš 10 SR invazyvumo potencialas buvo klasifikuojamas kaip didelis (klasifikacija pagal Sandvik ir kt., 2013), vienai rūšiai buvo nustatytas vidutinis invazyvumo potencialas ir dviejų rūšių ribotas invazyvumo potencialas.

Šio tyrimo metu buvo tikrinama ar SR druskingumo tolerancijos ribos yra limituojantis veiksnys dideliam invazyvumo potencialui. SR buvo suskirstytos į kategorijas pagal druskingumo tolerancijos zonas (druskingumo zonos pagal Venecijos sistemą, 6 priedas) ir palygintos pagal invazyvumo kategorijas (22 pav.). Rezultatai parodė, kad rūšys su platesniu druskingumo tolerancijos diapazonu gali turėti didesnį invazijos potencialą ir plitimas gali būti spartesnis. Lyginant SR turinčias pelaginę stadiją ir be jos buvo nustatyta, kad SR, turinčios pelaginę stadiją, turėjo didesnį nei vidutinį invazyvumo potencialą, lyginant su rūšimis be pelaginės stadijos (23 pav.).

Siekiant nustatyti MER metodo taikymo galimybes priklausomai nuo geografinės skalės, invazyvumo potencialo vertės buvo skaičiuojamos dviejuose skirtingo dydžio vandens telkiniuose. Šie vandens telkiniai skiriasi dydžiu ir aplinkos sąlygomis. Tyrimo metu buvo skaičiuojamas svetimkraštės rūšies dvigeldžio moliusko *Rangia cuneata* plitimo potencialas, ši rūšis pirmą kartą Baltijos jūros regione buvo aptikta 2010 m. Duomenų rinkinį sudarė rūšies aptikimo radimviečių koordinatės Vyslos lagūnoje (n = 159) ir Baltijos jūroje (n = 333) (19 pav.). Dvigeldžio moliusko *R. cuneata* vidutinis plitimo vertė Baltijos jūros buvo lygi 133 km per metus (2010–2016), maksimalus plitimo atstumas buvo lygus 763 km. Tuo tarpu Vyslos mariose plitimo vertė buvo lygi 16 km per metus (2010–2014) (pav. 24; 25).

DISKUSIJA

Diskusiją sudaro trys skyriai: *1) Rizikos ir poveikio vertinimo metodų kokybė, 2) Naujai atvykusių rūšių indeksas ir administracinių priemonių veiksmingumo matas, 3) Natūralaus ir antropogeninio plitimo nustatymas taikant MER metodą*

Pirmame skyriuje aptariami du šiame tyrime apžvelgti teisiniai dokumentai buvo sukurti skirtingais tikslais: pvz. ES reglamento (Europos Sąjunga) taikymo spektras platesnis ir skirtas invazinėms svetimoms rūšims, priklausančioms skirtingoms taksonominėms grupėms ir buveinėms, tuo tarpu TJO gairėse (TJO) pagrindinis dėmesys skiriamas kenksmingiems vandens organizmams ir patogenams, kurie pernešami vieninteliu plitimo keliu, t.y. laivais. Abiejų dokumentų palyginimas išryškino bendrus bruožus, vienas iš jų tai požiūris į biologinį saugumą. Ši lyginamoji analizė ypač aktuali, nes ES šalys turi įgyvendinti teisiškai patvirtintas priemones – BVTK (TJO 2004), kuri įsigaliojo 2017 m. (TJO 2017), ir ES reglamentas dėl įvedimo ir platinimo prevencijos ir valdymo invazinių svetimų rūšių (Europos Sąjungos 2014 m.). Pastarųjų dokumentų palyginimas ir kriterijų išskyrimas padėjo sudaryti išsamų ir integruotą požiūrį į rizikos vertinimo procesą.

Išanalizavus regioninius ir tarptautinius teisėkūros dokumentus, pvz., Biologinės įvairovės konvencijos (CBD 2011), Šiaurės Amerikos laisvosios prekybos sutarties (Generalinė apskaitos tarnyba, GAO), Azijos ir Ramiojo vandenyno ekonominio bendradarbiavimo (Williamson ir kt., 2002), ICES kodekso gairės, analizės rezultatai neatskleidė papildomų kriterijų, kuriuos būtų galima taikyti ar atsižvelgti vertinat rizikos vertinimo procesą. Barry ir kt. (2008), Dahlstromo ir kt. (2011) ir Davidas ir Gollasch (2015), kurie analizavo biologinio saugumo rizikos vertinimo norminius dokumentus ir bioinvazijos rizikos bei poveikio vertinimo metodus, taip pat neatskleidė kitų kriterijų, išskyrus tuos, kurie buvo taikyti šiame darbe. Manome, kad pagrindiniai principai ir rizikos vertinimo komponentai yra universalūs bioinvazijos rizikai ir metodams įvertinti. Biologinių invazijų poveikio kategorijos gali skirtis atsižvelgiant į įvertinimo apimtį ir turėtų būti naudojamos kaip papildomi kriterijai.

Metodų nuoseklumas turėtų duoti tikslius ir nuoseklius rūšies poveikio vertinimus, nepriklausomai nuo to, ar vertintojai yra skirtingi. Vertinimo metodų nuoseklumo lygis gali priklausyti ne tik nuo metodikos struktūros ar kitų charakteristikų, bet ir nuo naudojamų mokslinių įrodymų apie poveikį bei vertintojų kompetencijos lygio (Gonzalez-Moreno ir kt., 2019).

Metodo kokybę nusako pagrindinių principų (efektyvumas, skaidrumas, nuoseklumas, metodo aiškumas, rizikos valdymas, prevencija, mokslinis pagrindimas, nuolatinis metodikos atnaujinimas) atitikimas. Šiame darbe atliktos analizės rezultatai parodė, kad tik trys iš penkiolikos vertinimo metodų ir jų rezultatai buvo prieinami per internetinę duomenų bazę. „Skaidrumo“ principas laikomas vienu svarbiausiu, vertinant biologinių invazijų riziką ir poveikį. Metodai, kurie neatitinka skaidrumo principo, riboja prieigą prie rizikos vertinimo rezultatų, tuo tarpu sprendimus priimantys asmenys turėtų turėti prieigą prie visos informacijos tam, kad galėtų palyginti bioinvazijos rizikos ir poveikio vertinimo metodų naudojimą panašiose situacijose visame pasaulyje. Lehtiniemi ir kt. (2015) teigė, kad SR stebėjimo programos neturi jokios reikšmės, nebent gautos žinios yra tinkamu laiku panaudotos. Informacijos sklaida yra vienas svarbiausių skaidrumo principo aspektų, tai buvo daug kartų pabrėžiama tarptautiniu ir nacionaliniu lygmenimis (pvz., Awad ir kt., 2014; Sing and Tan 2018).

Šiame darbe apžvelgti bioinvazijos rizikos ir poveikio įvertinimo metodai buvo sukurti skirtingais tikslais: dėl biologinių invazijų valdymo sprendimų, palyginti ir nustatyti prioritetines svetimkraštes rūšis (Nentwig ir kt., 2010), nurodyti veiksmingą valdymo planą (Sandvik ir kt., 2013), „karštųjų taškų“ nustatymas (Drolet ir kt., 2016). Taip pat metodai turėtų atitikti aplinkos apsaugos politikos dokumentuose nurodytas gaires.

Antrame skyriuje aptariamos *nNIS* indekso vertinamojo vieneto vertės, kurios gali skirtis priklausomai nuo praktinių sumetimų, valdymo poreikių ir duomenų prieinamumo. Šiuo atveju vertinamasis vienetas buvo lygus šalies jūrų teritorijai, kuri priklauso DJE (Baltijos jūra) arba DJE subregionui. Toks skirstymas nustatomas tam, kad valdymo sprendimai dėl prevencinių priemonių būtų priimami nacionalinių valdžios institucijų lygiu. Mažiausias vertinamas vienetas galėtų būti uostas ir (arba) jo apylinkės, tuo atveju kai biologiniai tyrimai uostuose būtų privalomi, pavyzdžiui, norint priimti sprendimą dėl išimčių suteikimo pagal BVTK (David ir kt., 2013a, Galil ir kt., 2014; David ir Gollasch ir kt., 2015; Olenin ir kt., 2016), tačiau šiuo metu ne visos šalys privalo dalintis monitoringo duomenų informacija, todėl informacijos uostų lygmeniu yra nedaug. Nors SR plitimas keičia jų biogeografines ribas, norint jas valdyti, reikia keistis informacija tarp šalių, šalies institucijų, nevyriausybinių organizacijų ir tyrėjų. Duomenų rinkimas apie svetimų rūšių introdukciją visada yra problematiškas. Rūšių identifikavimas, neaiškūs įrašai ar nežinomi keliai ar poveikis apsunkina SR vertinimą. Tačiau molekuliniai įrankiai (Zaiko ir kt., 2015; Bucklin ir kt., 2016; Raupach ir kt., 2016; Viard ir kt., 2016) kartu su didėjančiu moksliniu susirūpinimu prisideda prie dabartinių svetimkraščių rūšių duomenų kokybės gerinimo (Olenin ir kt.). al. 2016). Deja, atkurti rūšių introdukcijų, kurios susijusios su žmogaus veikla, istoriją yra sudėtinga (Carlton 2009; Clavero ir kt., 2014), net ir pasitelkus naujai atplitusių svetimkraščių rūšių informaciją, galimų plitimo kelių analizę ar kitas žinios apie SR (pvz., Reusch ir kt., 2010). Šis tyrimas rodo, kad per pastaruosius devynerius metus žinių kiekis apie SR kilmę, poveikį ir atplitimo kelius sumažėjo. Šiame darbe pritaikytas *nNIS* indeksas galėtų suteikti papildomos informacijos, kuri būtina ankstyvam SR aptikimui (Magalleti ir kt., 2018 m.), išankstinio plitimo prognozavimo programoms (Roy ir kt., 2014 m.) bei įgyvendinat aplinkos apsaugos tikslus pagal JSPD siekiant geros aplinkos būklės (GAB). Be to, šis rodiklis leidžia įvertinti, ar įgyvendinamos vektorių ir plitimo kelių valdymo priemonės yra efektyvios. Naudojama AquaNIS duomenų bazė, nes šiuo metu ji yra vienintelė duomenų bazė, gebanti teikti duomenis, reikalingus *nNIS* indeksui skaičiuoti, ji reguliariai atnaujinama ICES jūrų organizmų plitimo ir perkėlimo darbo grupės duomenimis. Techniniai *nNIS* skaičiavimo pranašumai yra galimybė patikrinti ir užtikrinti atnaujinamos informacijos apie atplitimo įvykius šaltinius. Šio tyrimo rezultatai rodo, kad vidutinis SR skaičius per pastaruosius du dešimtmečius Baltijos jūros regione laikui bėgant keitėsi. Šio indekso vertinimai negalėtų būti atlikti be patikimos duomenų bazės (Olenin ir kt., 2016). Neatliekant nuolatinės duomenų priežiūros, atnaujinimo ir duomenų kokybės kontrolės, bazės naudingumas laikui bėgant sumažėja ir ji gali teikti klaidinančią informaciją (Costello ir Vanden Berghe 2006; Olenin ir kt., 2014; 2016). Pažymėtina, kad kai kuriais atvejais galimybė atskirti pirminį atplitimą nuo antrinio paplitimo gali būti labai ribota. Taip pat galimi daugybiniai SR atplitimai iš skirtingų DJE. Vienas iš daugybinio atplitimo pavyzdžių yra medūza *Mnemiopsis leidyi*, labai tikėtina, kad ši rūšis atplito per balastinius vandenis galimai iš dviejų skirtingų šaltinių vakarų Atlanto, Juodosios ir Šiaurės jūrų (Reusch ir kt., 2010). eDNR (aplinkos DNR) metodo taikymas galėtų padėti nustatyti tikslią SR kilmę ir atplitimo kelius ateityje (Rius ir kt., 2015; Solovjova ir kt., 2019).

Trečiame skyriuje. Biologinių invazijų dinamikai įtakos turi daugybė parametrų, tokių kaip SR gausumo reguliavimas erdvėje ir laike, augimo greitis, plitimo mechanizmas, demografinis ir aplinkos stochastiškumas (Kot ir kt., 1996; Neubert ir Caswell, 2000; Freckleton ir kt., 2006; Lewis ir kt., 2006; Sandvik ir kt., 2013). Siekiant nustatyti SR plitimo dėsningumus bei mechanizmus buvo analizuojami parametrai, turėję tiesioginę ir netiesioginę įtaką rūšies plitimui. Šie parametrai buvo reikalingi norint apibūdinti svetimos rūšies plitimo naujoje aplinkoje mechanizmus (pvz., Veit ir Lewis 1996). Nors kartais bandymą paaiškinti natūralų plitimą naudojant šalių, kuriose paplitusi SR, skaičių galima pervertinti, tačiau, vertinant svetimų rūšių riziką, svarbu apskaičiuoti numatomą jų plitimo greitį, kurį rūšis pasiekė ar pasieks anksčiau nekolonizuotose teritorijose (Sandvik ir kt., 2013).

Baltijos jūros regione aptiktų SR vyraujantis biologinis profilis: vystymosi metu turi pelaginę stadiją bei pasižymi plačiu druskingumo tolerancijos diapazonu (nuo limnetinės iki mezohalininės) ir turi didelį invazyvumo potencialą. Iki šiol egzistuoja ribotas metodų skaičius, kurie matuoja rūšių plitimą, ypač kuomet reikia palyginti SR pagal jų plitimą ar invazyvumo laipsnį. Dažniausias invazyvumo matas yra šalių skaičiaus, kuriose buvo aptikta rūšis, skaičiavimas (Molnar ir kt., 2008; Olenin ir kt., 2016), kiti autoriai siūlo skaičiuoti okupuotų regionų skaičių (Goodwin ir kt., 1999), taip pat labai dažnai siūloma atsižvelgti, kokiuose bioregionuose ar ekoregionuose rūšis yra paplitusi. Dar kiti autoriai teigia, kad SR biologinės savybės ir sąveika su kitomis rūšimis naujoje vietoje lemia, ar plačiai plis SR. Kai kurios išlieka gana lokalizuotos atplitimo regione, o kitos gali plisti plačiai. Atskirti šias dvi rūšių grupes yra labai sudėtinga, o kartais net neįmanoma.

Remiantis neseniai atlikto tyrimo rezultatais, kai laivų balastiniuose vandenyse buvo nustatyta plati taksonominė įvairovė (Drake ir Lodge 2007; Wu ir kt., 2017; Cabrini ir kt., 2018). Pažymėtina, kad šiame tyrime MER verčių skaičiavimo vertės buvo apskaičiuotos rūšims, kurios gali plisti balastinių vandenų rezervuare. Viena iš tyrimo hipotezių buvo ta, kad rūšys, kurių gyvavimo ciklas susijęs su pelagine vystymosi stadija, turi daugiau galimybių plisti į kitus regionus laivų balastiniuose vandenyse. Šiame darbe tarp taksonominių grupių buvo nustatytos skirtingos MER vertės, taip pat skirtumai nustatyti tarp rūšių, turinčių pelaginę stadiją ar be jos. Analizės duomenys parodė, kad MER metodas gali būti taikomas invazyvumo potencialui nustatyti, ypač norint palyginti rūšis ir jų invazijos galimybes, tačiau tam reikėtų naudoti patikrintus ir aiškius duomenis apie plitimo įvykius.

Moliusko *R. cuneata* (G. B. Sowerby I, 1832) (Bivalvia, Mactridae) kilmės regionas yra Meksikos įlanka. Ši rūšis plinta Šiaurės Europos vandenyse (AquaNIS 2019; Verween ir kt, 2006). Pirmą kartą ji buvo aptikta Belgijoje 2005 m. (Verween ir kt., 2006) ir nuo to laiko išplito į estuarijas pietiniuose Šiaurės jūros regionuose (Neckheim 2013; Bock ir kt., 2015; Gittenberger ir kt., 2015; Wiese ir kt., 2016; Kerckhof ir kt., 2018). Pietrytinėje Baltijos jūros dalyje rūšis aptikta apie 2010 m., spėjama, kad atplito vandens keliu, vedančiu į Kaliningrado uostą, Vyslos lagūnos regione Rusijos federacijoje (Ezhova 2012; Rudinskaya and Gusev 2012). 2011 m. buvo užfiksuota Vyslos mariose, Lenkijos valstybei priklausančioje dalyje (Warzocha ir Drgas 2013; Janas ir kt., 2014; Warzocha ir kt., 2016). Galiausiai 2013 m. rūšis buvo užfiksuota Lietuvos pakrantės vandenyse (Solovjova 2014), o toliau plito į šiaurę - Pernu įlanką, Rygos įlanką (Möller and Kotta 2017). Vėliau rasta Vokietijos ir Švedijos vandenyse (AquaNIS 2019).

Norėdami išsiaiškinti MER metodo taikymo efektyvumą priklausomai nuo gegrafinio plitimo regiono dydžio, vertinome moliusko *R. cuneata* invazyvumo potencialą Baltijos jūroje ir pusiau uždaroje sistemoje Vyslos lagūnoje (Lenkija). Palyginus plitimo vertes skirtinguose vandens telkiniuose, paaiškėjo, kad moliusko *R. cuneata* paplitimo vertės skiriasi, Vistulos lagūnoje 16 km per metus, Baltijos jūroje 133 km per metus. Nors srovės Baltijos jūroje yra silpnos, vidutinis greitis apie 5 cm/s, audrų metu vėjo sukeltos srovės gali siekti 50 m/s, sąsiauriuose gali siekti iki 100 cm/s. Pažymėtina, kad pelaginės stadijos lervutės gali plisti didelius atstumus. Nors apie moliusko *R. cuneata* galimą pelaginės stadijos lervutės plitimą didelius atstumais duomenų neradome, tačiau žinoma, kad moliusko dydis būti įvairus 4–40 mm, o lervų gyvybingumas – 7 dienos. Šiuo atveju darome prielaidą, kad Vyslos lagūnoje plitimas buvo natūralus, tuo tarpu atsižvelgiant į dideles vidutines *R. cuneata* plitimo vertes ir maksimalius atstumus visoje Baltijos jūroje, mažai tikėtina, kad rūšis galėtų plisti natūraliai dėl srovių. Viena iš plitimo hipotezių ta, kad rūšies plitimą galėjo lemti uosto farvaterio gilinimo veikla 2008 m. Žinoma, kad gilinimo darbams buvo naudojama kasimo įranga kuri buvo atgabenta iš Nyderlandų (Verween ir kt. 2006). Šio dvigeldžio atsiradimą Lietuvos vandenyse galima paaiškinti ir natūraliu atplitimu iš kaimyninių šalių (Lenkijos ar Rusijos federacijos (Warzocha ir Drgas 2013; Janas ir kt., 2014; Warzocha ir kt., 2016). Naujausi įrašai iš Estijos, Pernu įlankos (Möller ir Kotta 2017) ir Švedijos (neskelbti duomenys, „AquaNIS“) rodo moliusko sugebėjimą plisti toliau į šiaurės rytinę Baltijos jūros dalį (22 pav.). Norint tinkamai aprašyti svetimos rūšies plitimo naujoje aplinkoje mechanizmus reikia įvertinti daugybę parametrų (pvz., Veit ir Lewis, 1996), beveik neįmanoma atlikti tikslią plitimo prognozę, remiantis tik aptikimo duomenimis. Taip pat reikia duomenų apie vietinių rūšių populiacijų dinamiką, kaip šie pokyčiai kinta laike ir kaip šie individai plinta, iki šiol yra labai mažai duomenų rinkinių su aukšto kokybės patikimumu (Sandvik ir kt., 2013).

IŠVADOS

1. Palyginus ES invazinių svetimų rūšių reglamentą (2018, Nr. 968/2018), susijusį su invazinių svetimų rūšių rizikos vertinimu, ir TJO (2007 m.) Rizikos vertinimo gaires pagal Reglamentą A-4 paaiškėjo, kad bioinvazijos poveikis ir rizikos vertinimo metodai turėtų būti grindžiami aštuoniais pagrindiniais rizikos vertinimo principais, 29 rizikos vertinimo komponentais ir keturiais pagrindiniais poveikio tipais (žmonių sveikata, ekonomika, gamtinė aplinka, socialinės bei kultūrinės vertybės). Remiantis minėtais kriterijais, buvo sukurta atitinkama vertinimo sistema;
2. Įvertinus 15 pasirinktų bioinvazinių poveikių ir rizikos įvertinimo metodų, galima daryti išvadą, kad kuo metodas labiau atitinka pagrindinius principus („skaidrumas“, „nuoseklumas“, „suprantamumas“ ir kt.), tuo aukštesnė jo kokybė. Be to, metodo kokybė priklauso nuo to, ar pilnai įtraukiami rizikos ver-

tinimo komponentai, o bioinvazijos poveikio kategorijos gali skirtis ir turėtų būti parenkamos atsižvelgiant į rizikos vertinimo tikslą. Dažniausiai metoduose taikomos poveikio gamtinei aplinkai kategorijos (100%), po to seka – poveikis ekonomikai (60%) ir žmonių sveikatai (57%), o mažiausiai dėmesio buvo skiriama socialinėms ir kultūrinėms vertybėms (53%).

3. Atlikus analizę paaiškėjo, kad nors nė vienas iš metodų visiškai neatitiko visų kriterijų, aukščiausią įvertinimą gavo Australijos SBRA (Species Biofouling Risk Assessment) metodas, po jo eina Belgijos HARMONIA + ir britų AS-ISK metodai. Sukurta kriterijų vertinimo sistema rekomenduojama taikyti, kuriant ir tobulinant rizikos ir poveikio vertinimo metodus, ypač tiems, kurie skirti balastiniam vandeniui tvarkyti arba kurie skirti vykdyti ES reglamentą (2018).
4. Taikant *nNIS* indeksą paaiškėjo, kad naujų rūšių skaičius visame Baltijos jūros regione (nNIS L2) padidėjo nuo 20 2000–2009 m. iki 25 2010–2018 m., tuo tarpu didesnio biogeografinio regiono (Baltijos jūra + Šiaurės jūra, nNIS L3) lygiu naujų atvykėlių skaičius sumažėjo nuo 9 iki 6 rūšių. Tai galima priskirti prie antrinių SR plitimo būdų, nes analizė parodė, kad du pagrindiniai plitimo vektoriai yra plitimas iš kaimyninių šalių ir laivų. Sumažėjimas buvo nustatytas 2010–2018 m. laikotarpiu, nustatyta, kad atplinta atitinkamai per laivus (39% ir 34%) ir iš kaimyninių šalių (44% ir 29%).
5. Taikant vidutinio plitimo vertės (MER) metodą, iš atrinktų dešimties Baltijos jūros rūšių didžiausia vertės nustatyta mizidei *Hemimysis anomala*, kurios MER = 168 km per metus. Rūšys, kurios turi pelaginę vystymosi stadiją ir turi platų druskingumo tolerancijos diapazoną, pasižymi aukštesnėmis MER vertėmis. Invazinio dvigeldžio moliusko *Rangia cuneata* natūralaus plitimo vertė buvo MER = 16 km per metus Vyslos lagūnoje, o visos Baltijos jūros mastu buvo MER = 133 km per metus, tai reiškia, kad ši rūšis Baltijos jūroje plito pernešama dėl žmogaus veiklos
6. MER metodas gali būti veiksmingas būdas įvertinti invazyvumą, kuris pašalina subjektyvumą, paprastai susijusį su invazyvumo apibrėžimu, pagrįstu poveikio vertinimu. Sujungiant su *nNIS* indeksu, MER metodas gali būti naudingas aplinkos būklės įvertinimo parametras (pvz., HELCOM 2018), jis gali būti taikomas nustatant valdymo veiksmus pagal prioritetus, taip pat naudojant papildomą informaciją apie naujų rūšių plitimo kelius / vektorius, kuri pasiekiama per pasaulinę informacinę sistemą, tokią kaip „AquaNIS“.

9

Annexes

***Annex 1.* Detailed descriptions on categories of impact types**

Impact types Category	COMMENT	REFERENCE
Human health		
Human pathogens	Organism is pathogen and poses a threat to human health, consequences may be: mortality, illness, poisoning, toxicity, pain, irritation. Pathogens as *Vibrio cholerae, Escherichia coli,* and *Enterococci.*	AquaNIS 2019; Olenin et al. 2016; Vilà and Hulme 2017.
Human parasites	Organism is parasite and poses a threat to human health; consequences may be: mortality, illness, poisoning, toxicity, pain, irritation.	Essl et al. 2011; Baker et al. 2008; Vilà and Hulme 2017.
Toxic	Organism has toxic compounds and poses a threat to human health, their flesh is toxic if consumed; Organisms produce chemical toxins which are used to kill or incapacitate prey or as a defense against predators.	Katsanevakis et al. 2014; Essl et al. 2011; Vilà and Hulme 2017.
Poisoning	Organism is poisoning to human; can decrease food security, worsen human health, increase livelihood vulnerability.	Copp et al. 2009; Copp et al. 2016; Nentwig et al. 2010; Vilà and Hulme 2017.
Venomous organisms	Venomous animals deliver toxins as venom through a bite, sting, or other specially evolved mechanism.	Nentwig et al. 2010; Vilà and Hulme 2017.
General impact	General impact on human health, other risk (not mentioned above) to human health, to cause discomfort or pain to humans, irritation, transmission of diseases, allergies, injuries, miscellaneous.	Copp et al. 2016; Essl et al. 2011; Mendoza et al. 2009; Nentwig et al. 2010; Vilà and Hulme 2017.
Environmental		
Pest on native species	Organism can be pest and may have impact on native species.	Copp et al. 2016; Nentwig et al. 2010; Mendoza et al. 2009; Vilà and Hulme 2017.
Pathogen on native species	Organism can be pathogen and may have impact on native species.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Vilà and Hulme 2017.

Impact types Category	COMMENT	REFERENCE
Parasite on native species	Organism can be parasite or pose parasitism on native species causing impact on native species.	Olenin et al. 2007; Vilà and Hulme 2017; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Vilà and Hulme 2017.
Pest vector	Organism may transfer their pest/pathogens/parasite (native or non-native) to the native species, which in turn disfavors native species and favors the invader itself.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Vilà and Hulme 2017.
Pathogen vector		
Parasite vector		
Habitat change or loss	Considering the habitat alteration or loss, fragmentation and quality, type and size of affected habitat, reduced suitability.	Olenin et al. 2007; Baker et al. 2008; Vilà and Hulme 2017.
Biodiversity alteration	Biodiversity or richness alteration, had negative, positive impact upon native biota.	Manchester et al. 2000; Olenin et al. 2007; Katsanevakis et al. 2014; Essl et al. 2011; Baker et al. 2008; Nentwig et al. 2010; Mendoza et al. 2009; Vilà and Hulme 2017.
Species abundance	General impact on native species abundance, increase or decrease of native species.	Olenin et al. 2007; Katsanevakis et al. 2014; Sandvik et al. Nentwig et al. 2010; Vilà and Hulme 2017.
Keystone species	General impact on keystone species, decrease or increase of abundance of keystone species.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Vilà and Hulme 2017.

Impact types Category	COMMENT	REFERENCE
Threatened or endangered species	General impact, decrease or increase threatened or endangered species.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Vilà and Hulme 2017.
Toxicity on native species	Organism has toxic compounds and poses a threat to native species. Organisms produce chemical toxins which are used to kill or incapacitate prey or as a defense against predators.	Olenin et al. 2007; Vilà and Hulme 2017; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Predation	Predation refers to an interaction between two organisms, predator and prey, where there is a flow of energy from one to another. Process which caused declines.	Manchester et al. 2000; Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Herbivory/grazing	Organism feeds on plants (aquatic plants, benthic algae and phytoplankton) and/or sessile animals organisms.	Manchester et al. 2000; Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Competition	Interaction between two or more organisms or species in which both the organisms or species are affected or harmed variously.	Manchester et al. 2000; Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Hybridization	Organism impact on genetic diversity and genetic structure on native species, genetic integrity of species, changes genetic constitution and phenotype.	Manchester et al. 2000; Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.

Impact types Category	COMMENT	REFERENCE
General ecosystem services	Changes to biological, chemical and physical properties of aquatic ecosystems.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Nutrient regime alterations	Increase or decrease of nutrient content.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009; Covich et al. 1999
Hydrological cycle changes	Changes to hydrographic regimes and topography.	Olenin et al. 2007; D'hondt et al. 2015; Mendoza et al. 2009.
Food web changes	Changes of the food web as a result of addition or reduction of functional groups within trophic levels.	Olenin et al. 2007; Essl et al. 2011; Baker et al. 2008; Sandvik et al. 2013; Nentwig et al. 2010; Blackburn et al. 2014, D'hondt et al. 2015; Mendoza et al. 2009.
Economy		
Fisheries	Economic components within an ecosystem that provide a current or potential economic values, consumer reaction, alteration to fishery.	Manchester et al. 2000; Emerton and Howard 2008; A. Dahlstrom et al. 2011.
Aquaculture	Gain or loss on farming aquatic organisms.	Manchester et al. 2000; Emerton and Howard 2008.
Biotechnology	Changes in abundance of medical marine plants, algae and fisheries resources.	Emerton and Howard 2008.
Cost of changes to environment	Changes of environment causing economic consequence, loss of nursery areas, commercial species, commercially relevant infrastructure.	Manchester et al. 2000; Emerton and Howard 2008; Booy et al. 2017
Navigation	Canals, loss of access due to choking of waterways, port infrastructure, offshore wind and tidal generation, desalination plants.	Emerton and Howard 2008.
Changes to wildlife habitat	Impact on nature reserves, costs to remove or prevent non-indigenous species.	Manchester et al. 2000; Emerton and Howard 2008.

Impact types Category	COMMENT	REFERENCE
Irrigation and abstraction	Irrigation and abstraction of water or irrigation canals, abstraction to power plants and municipal supplies.	Emerton and Howard 2008.
General management costs	Research and administration, monitoring, quarantine.	Emerton and Howard 2008.
Tourism	Impact on tourism, touristic sites, decrease or increase of value touristic sites, hiker and ecotourist visitations.	Emerton and Howard 2008.
Health care costs	Health hazards which leads to economic costs.	Nentwig et al. 2010; Emerton and Howard 2008.
Opportunity costs	Opportunity costs approach may serve to justify accepting the largest, and possibly most environmentally damaging, development projects. These costs can be explored via scenarios of future.	Crowards1998; Turner et al. 2008.
Social and cultural		
Recreation and tourism locations	Symbolic-aesthetic values for human use pleasure of a species or habitats.	Katsanevakis et al. 2014; Emerton and Howard 2008.
Spiritual proposes and religious locations	Species, locations, habitats used for spiritual proposes; iconic or spiritual value, including locations that create a sense of local, regional, or national identity.	Katsanevakis et al. 2014; Emerton and Howard 2008.
Education and research	Species, locations, habitats used for education and research	Katsanevakis et al. 2014; Ojaveer et al. 2015; Emerton and Howard 2008.
Interference with monitoring	Interference with long-term or short-term monitoring	Olenin et al. 2016; Emerton and Howard 2008.

Annex 2. **Detailed description of RA methods key principles and assessment process**

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehensiveness	Comments Risk Management	Comments Precautionary	Comments Science based	Continuous improvement
AS-ISK	Calculations described; result is calculated automatically. The use of an offline application, definitions of all parameters provided, the calculation scheme is clear.	The assessment is clearly documented, available on request from the authors (not freely available online).	The consistency of a method was tested, the results are published in a peer-reviewed literature (Copp et al. 2016)	Considers three categories (EN, EC, HH).	Categories of risk, from unacceptable (danger to human health) to acceptable, questions on management decision.	Level of confidence for each risk assessment step, and final risk score, clear instructions to define uncertainty.	The method assesses biological traits, environmental tolerance limits of species and impacts. Method uses quantitative or/ and qualitative data.	Method has been updated since original version (Pheloung et al. 1999; Copp et al. 2013; Tricarico et al. 2010; Papavlasopoulou et al. 2014).
BINPAS	Definitions of all parameters provided, the calculation scheme is clear, the result is obtained automatically using an online platform http://www.corpi.ku.lt/databases/index.php/binpas.	The reasoning and evidence supporting assessment is documented, and available via a free online information system. http://www.corpi.ku.lt/databases/index.php/binpas.	The assessment of the consistency of a method is not available publically.	Considers one category (EN).	Five levels of risk (minimum and high), except human health.	Level of confidence for each risk assessment step.	Method takes into account impacts, assess biological traits, part of assessment is based on quantitative or qualitative/descriptive data.	Method has been updated since original version biopollution level (BPL) (Olenin et al., 2007) was later computerized and renamed as BINPAS/ Biopollution assessment system.

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehensiveness	Comments Risk Management	Comments Precautionary	Comments Science based	Continuous improvement
CIMPAL	Definitions of all parameters provided, the calculation scheme is clear, the result is obtained either automatically using an online platform or by a questionnaire.	The reasoning and evidence supporting the assessment is not provided, available on request from the authors (not freely available online).	The assessment of the consistency of a method is not available publically.	Considers one category (EN).	Index defines the level of risk in general, gives sites specific value according environmental impact.	The ranking of sites based on the two decision-making strategies: the uncertainty-averse and the precautionary approach.	The method takes into account impacts assess environmental tolerance limits and habitat physical characteristics.	Only original version exists, has no updated version until now.

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehen-siveness	Comments Risk Management	Comments Precaution-ary	Comments Science based	Continuous improvement
CMIST	The use of a method is supported by an application freely available online questionnaire, definitions of all parameters provided, the calculation scheme is clear, the result is obtained automatically.	The reasoning and evidence supporting the assessment is documented, available via a free online information system. http://www.bio.gc.ca/science/monitoring-monitorage/cmist/index-en.php	The consistency of a method was tested (Drolet et al. 2016).	Considers one category (EN).	The method defines final risk in general (possible threating categories, except human health).	Incorporates level of confidence for all risk assessment steps (detailed information in the manual how to assess uncertainty), but no confidence level for the final score.	The method assesses biological traits (such as establishment, frequency number of species arrivals, reproductive requirements, potential dispersal), environmental tolerance limits, assessment is based on quantitative field and/or experimental data.	Method has been updated since original version, is a modification of the Alberta Risk Assessment Tool (IASWG 2009; Drolet et al. 2014; Drolet et al. 2015;).

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehensiveness	Comments Risk Management	Comments Precautionary	Comments Science based	Continuous improvement
GABLIS	A method is represented by a questionnaire, the calculation scheme is clear.	The reasoning and evidence supporting the assessment is documented and available on request from the authors (not freely available online).	The assessment of the consistency of a method is not available publically.	Considers three categories (EN, EC, HH).	The method defines classification of species into ranks, management question included.	No level of confidence is included.	Data from scientific reports, peer-reviewed publications, expert judgement used. Indirectly assess biological traits (reproduction capacity, spread capacity), environmental tolerance limits.	Only original version exists, has no updated version until now (Essl et al. 2012)
GB NNRA	A method is represented questionnaire (Identification sheets) which is available online. No calculation scheme is included; the assessment is qualitative. http://www.nonnativespecies.org/alerts/index.cfm	The reasoning and evidence supporting the assessment is documented, and available via a free online information system. http://www.nonnativespecies.org/alerts/index.cfm	The assessment of the consistency of a method is not available publically.	Considers four categories (EN, EC, HH, SC)	The method defines the categories of risk in general, no definition of the magnitude of risk.	Level of confidence for each assessment steps, including for the final risk score.	Assessment of biological traits, environmental tolerance limits, probability of entry, establishment, spread and impacts.	Method has been updated since original version.

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehensiveness	Comments Risk Management	Comments Precautionary	Comments Science based	Continuous improvement
GEIAA	Definitions of all parameters provided, the calculation scheme is clear, the result is calculated automatically.	The reasoning and evidence supporting the assessment is available via a free online information system. https://www.artsdatabanken.no	The assessment of the consistency of a method is not available publically.	Considers one category (EN) (detailed SD, CO, PRP, HP, TI, TG, PR, PH)	The method defines the categories of impacting in general five categories, except human health.	Incorporates level of confidence for each assessment step, but not for the final score. No detailed information for uncertainty.	The method assesses biological traits (reproduction strategy, reproduction capacity, generation time, expected population lifetime, expansion velocity).	Only original version exists, has no updated version until now (Sandvik et al. 2013)
GISS	A method is represented by a questionnaire. The calculation scheme is clear. Supplementary information GISS Handbook.	The reasoning and evidence supporting the assessment is documented, the assessment is available on request from the authors.	The consistency of a method was tested (Strubbe et al. 2011, Evans et al. 2015).	Considers two categories (EN, EC, HH, HS, HI).	The method defines the level of risk, including risk to human health.	Incorporates level of confidence for all risk assessment steps, level of confidence for the final score.	The method uses literature overview, published information, do not includes the biological traits or environmental tolerance limits.	Method has been updated since original version (Nentwig et al. 2016, Blackburn et al. 2014)

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehen-siveness	Comments Risk Management	Comments Precaution-ary	Comments Science based	Continuous improvement
GISS IUCN	A method is represented by a questionnaire. Definitions of all parameters pro-vided, the calcula-tion scheme is clear, the result is calculated auto-matically.	The reasoning and evidence supporting the assessment is documented, the assessments is available on request from the authors.	The assess-ment of the consistency of a method is not available publi-cally.	Considers one category (EN).	The method defines the categories of impacting in general (pos-sible threating categories, except human health).	Incorporates level of confidence for all steps and final risk score. De-scription of assessment for confi-dence level.	The method takes into ac-count only impacts, based on literature overview, do not includes the biologi-cal traits or environmental tolerance limits (Blackburn et *al.* 2014).	Only original version exists, has no updated version until now (Blackburn et *al.* 2014)
HARMONIA+	The method is available online, all definitions provided, the cal-culation scheme is clear, the result is obtained auto-matically. http://ias.biodi-versity.be	The reasoning and evidence supporting the assessment is documented and available via a free online infor-mation system https://ias.biodi-versity.be/species/risk	The consistency of a method was tested (D'hondt et al. 2015).	Considers three categories (EN, EC, HH, HI).	The method clearly defines the categories of risk, from unacceptable to acceptable, including deci-sion making.	Incorporates level of confidence for all risk assessment steps, but not for the final score.	The method assesses bio-logical traits, environmental tolerance lim-its, assessment is based on quantitative field and/or experimental data.	Only original version exists, has no updated version until now (D'hondt et al. 2015)

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehen-siveness	Comments Risk Management	Comments Precaution-ary	Comments Science based	Continuous improvement
TRAAIS	A method is represented by a questionnaire, the calculation scheme is clear, the assessment is qualitative. http://www.sask-invasives.ca/file/CEC%20risk%20guidelines.pdf	The reasoning and evidence supporting the assessment is documented, the assessments is available on request from the authors.	The assess-ment of the consistency of a method is not available publi-cally.	Considers two categories (EN, EC).	The method defines the categories of risk in general (possible threat-ing categories, except human health), no level of risks described.	Incorporates level of confidence for all risk assessment steps, but not for the final score.	The method assesses bio-logical traits, environmental tolerance lim-its, assessment is based on quantitative field and/or experimental data.	Only original version exists, has no updated version until now.
GLOTSS	A method is represented by a questionnaire, the calculation scheme is clear, the assessment is qualitative.	The reasoning and evidence is docu-mented, available via a free online information system http://conserveonline.org/workspaces/global.invasive.assessment	The assess-ment of the consistency of a method is not available publi-cally.	Considers one category (EN)	The method defines the categories of risk in general, no level of risks described, man-agement ques-tion included.	Incorporates level of con-fidence docu-mentation source, but not for the final score.	Indirectly as-sess biological traits (invasive potential, spread), assess-ment is based on quantitative field and/or experimental data.	Only original version exists, has no updated version until now (Molnar et al. 2008).

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehen-siveness	Comments Risk Management	Comments Precaution-ary	Comments Science based	Continuous improvement
WISC	A method is represented by a questionnaire, the calculation scheme is clear, the assessment is qualitative.	The reasoning and evidence supporting the assessment is documented, the assessment is available on request from the authors.	The assess-ment of the consistency of a method is not available publi-cally.	Considers two categories (EN, EC).	The method defines the categories of risk in general, level of risks described, man-agement ques-tion included.	Incorporates level of confidence for all risk assessment steps, and for the final score.	Indirectly as-sess biological traits (poten-tial for entry, spread), assess-ment is based on quantitative field and/or experimental data.	Method has been updated since original version, adapted from Alaska's ranking system.
SBRA	A method is represented by a questionnaire, the calculation scheme is clear, the assessment is qualitative.	The reasoning and evidence supporting the assessment is documented, the assessments is available on request from the authors.	The assess-ment of the consistency of a method is not available publi-cally.	Considers four categories (EN, EC, HH, SC).	The method defines the categories of risk in general, level of risks described, man-agement ques-tion included.	Incorporates uncertainty for risk part of assess-ment.	Assess bio-logical traits, environmental tolerance lim-its, assessment is based on quantitative field and/or experimental data.	Method has been updated since original version.

Bioinvasion risk and impact assessment methods	Comments Effectiveness	Comments Transparency	Comments Consistency	Comments Comprehensiveness	Comments Risk Management	Comments Precautionary	Comments Science based	Continuous improvement
RABW	A method is represented by a questionnaire, the assessment is qualitative.	The reasoning and evidence supporting the assessment is documented, the assessments is available on request from the authors.	The assessment of the consistency of a method is not available publically.	Considers four categories (EN, EC, HH, SC).	The method clearly defines the categories of risk, from unacceptable to acceptable, including decision making.	Incorporates level of confidence for all risk assessment steps.	Assess biological traits, environmental tolerance limits, assessment is based on quantitative field and/or experimental data.	Only original version exists, has no updated version until now.

Explanation: Environmental - EN, human health - HH, economic – EC, social and cultural – SC, HS – human social life, HI – human infrastructure;

Annex 3. **Screening results for compliance of RA methodologies for components**

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
General information	**Art 5(1) (a) - a description of the species with its taxonomic identity, its history, and its natural and potential range**		**5/5**	**5/5**	**4/5**	**3/5**	**5/5**	**3/5**	**5/5**	**5/5**	**5/5**	**5/5**	**5/5**	**4/5**	**4/5**	**4/5**	**5/5**
	1. Description of species		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2. The scope of the risk assessment shall be clearly delineated		1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
	3. The description of the taxonomic identity of the species		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	4. The description of the history of the species	■▲□	1	1	0	0	1	0	1	1	1	1	1	1	1	0	1
	a. Information on countries invaded		+	-	-	-	+	-	+	+	+	+	+	+	+	-	+
	b. Indication of the timeline of the first observations		+	+	-	-	-	-	-	-	+	-	+	-	-	-	-
	c. Establishment and spread		+	-	-	-	-	-	-	-	-	+	+	-	-	-	-
	5. The description of the natural and potential range of the species	■□	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1
Reproduction and spread	**Art 5(1) (b)- a description of its reproduction and spread patterns and dynamics including an assessment of whether the environmental conditions necessary for its reproduction and spread exist**		**3/3**	**1/3**	**2/3**	**3/3**	**3/3**	**3/3**	**3/3**	**0/3**	**0/3**	**3/3**	**2/3**	**3/3**	**2/3**	**2/3**	**3/3**

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	1. The descriptions of reproduction and spread patterns	■□	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1
	a. The species life history		+	+	-	+	+	+	+	-	-	+	+	+	-	-	+
	b. Behavioural traits		+	-	-	+	+	+	-	-	-	+	+	-	+	-	-
	c. Ability to establish and spread		+	-	-	+	+	+	+	-	-	+	+	+	+	+	+
	d. Reproduction or growth strategy		+	-	-	+	+	+	+	-	-	+	-	+	-	-	-
	e. Dispersal capacity		+	-	-	+	+	+	+	-	-	+	-	+	+	+	+
	f. Longevity		-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	g. Environmental and climatic requirements		+	-	-	-	+	+	-	-	-	+	-	+	-	-	+
	h. Specialist or generalist characteristics			-	-	+	-	-	-	-	-	-	-	-	-	-	-
	2.The description of the reproduction patterns and dynamics	■□	1	0	1	1	1	1	1	0	0	1	1	1	0	0	1
	a. A list and description of the reproduction mechanisms		+	-	-	+	+	+	+	-	-	+	+	+	-	-	-
	b. Suitable environmental conditions for reproduction exist in the risk assessment area, e.g. number of gametes, eggs or propagules, reproductive cycles per year		-	-	+	-	-	+	+	-	-	+	-	-	-	-	-

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	c. For each of those reproduction mechanisms in relation to the environmental conditions in the risk assessment area		+	-	-	-	+	+	-	-	-	+	-	+	-	-	+
	3. The description of the spread patterns and dynamics shall include all of the following elements	■□	1	0	1	1	1	1	1	0	0	1	0	1	1	1	1
	a. Description of the spread mechanisms		+	-	-	+	+	-	+	-	-	+	-	+	+	-	-
	b. Suitable environmental conditions for the species' spread		+	-	+	+	+	+	-	-	-	+	-	+	-	+	+
	c. Rate of each of those spread mechanisms in relation to the environmental conditions		+	-	-	-	+	+	-	-	-	+	-	+	-	+	+
Pathways	**Art 5(1) (c) - a description of the potential pathways of introduction and spread of the species, both intentional and unintentional, including where relevant the commodities with which the species is generally associated**		**5/7**	**0/7**	**6/7**	**2/7**	**5/7**	**7/7**	**1/7**	**0/7**	**4/7**	**7/7**	**7/7**	**7/7**	**4/7**	**7/7**	**6/7**
	1. All relevant pathways for introduction as well as for spread	▲□	0	0	1	0	1	1	1	0	1	1	1	1	1	1	0

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	2. The description of intentional pathways of introduction	▲□	1	0	1	0	1	1	0	0	1	1	1	1	1	1	1
	a. A list and description of pathways with an indication of their importance and associated risks (e.g. The likelihood of introduction into the risk assessment area; the likelihood of survival, reproduction or increase during transport and storage; the ability and likelihood of transfer, details about the specific origins and end points of the pathways)		+	-	+	-	+	+	-	-	+	+	+	+	+	+	+
	b. An indication of the propagule pressure (e.g. The estimated volume or number of specimens, or the frequency of passage through those pathways), including the likelihood of reinvasion after eradication.		-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
	3. The description of unintentional pathways of introduction	▲□	1	0	1	0	1	1	0	0	1	1	1	1	1	1	1

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	a. A list and description of pathways with an indication of their importance and associated risks (e.g. The likelihood of introduction into the risk assessment area, the likelihood of survival, reproduction or increase during transport and storage; the likelihood of non-detection at the entry point; the ability and likelihood of transfer from those pathways to a suitable habitat or host), details about the specific origins and end points of the pathways		+	-	+	-	+	+	-	-	+	+	+	+	+	+	+
	b. An indication of the propagule pressure (e.g. The estimated volume or number of specimens, or the frequency of passage through those pathways)		-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
	4. The description of commodities with which the introduction of the species is generally associated	▲□	0	0	1	0	1	1	0	0	1	1	1	1	1	1	1

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	a. A list and description of commodities with an indication of associated risks (e.g. The volume of trade flow; the likelihood of the commodity being contaminated or acting as a vector)		-	-	+	-	+	+	-	-	+	+	+	+	+	+	+
	5. The description of intentional pathways of spread	▲□	1	0	1	1	0	1	0	0	0	1	1	1	0	1	1
	a. A list and description of pathways with an indication of their importance and associated risks (e.g. The likelihood of spread within the risk assessment area, based on those pathways; the likelihood of survival, reproduction or increase during transport and storage; the ability and likelihood of transfer from those pathways to a suitable habitat or host), including, where possible, details about the specific origins and end points of the pathways		+	-	+	-	-	+	-	-	-	+	+	+	-	+	+

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	b. An indication of the propagule pressure (e.g. The estimated volume or number of specimens, or the frequency of passage through those pathways), including the likelihood of reinvasion after eradication		-	-	-	+	-	-	-	-	-	-	+	+	-	+	+
	6. The description of unintentional pathways of spread	▲□	1	0	1	0	0	1	0	0	0	1	1	1	0	1	1
	a. A list and description of pathways with an indication of their importance and associated risks (e.g. The likelihood of spread within the risk assessment area, the likelihood of survival, reproduction or increase during transport and storage; the ease of detection; the ability and likelihood of transfer from those pathways to a suitable habitat or host), including details about the specific origins and end points of the pathways		+	-	+	-	-	+	-	-	-	+	+	+	-	+	+

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	**BINPAS**	**CIMPAL**	**CMIST**	**GABLIS**	**GB NNRA**	**GEIAA**	**GISS**	**GISS IUCN**	**HARMO-NIA+**	**TRAAIS**	**SBRA**	**GLOTSS**	**WISC**	**RABW**
	b. An indication of the propagule pressure (e.g. The estimated volume or number of specimens, or the frequency of passage through those pathways), including the likelihood of reinvasion after eradication		-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	7. The description of commodities with which the spread of the species is generally associated	▲□	1	0	0	1	1	1	0	0	0	1	1	1	0	1	1
	a. The volume of trade		-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
	b. The likelihood of a commodity being contaminated		+	-	-	+	+	+	-	-	-	+	+	+	-	-	+
	c. The likelihood of a commodity acting as vector		-	-	-	+	+	+	-	-	-	+	+	+	-	+	+
Stages of invasion process	**Art 5(1) (d) - a thorough assessment of the risk of introduction, establishment and spread in relevant biogeographical regions in current conditions and in foreseeable climate change conditions**		**2/3**	**1/3**	**2/3**	**2/3**	**2/3**	**3/3**	**2/3**	**1/3**	**0/3**	**3/3**	**2/3**	**2/3**	**2/3**	**2/3**	**2/3**
	1. The thorough assessment shall provide insights into the risks	■▲□	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	a. Insights into the risks of a species' introduction into relevant biogeographical regions in the risk assessment area		-	-	+	+	+	+	+	-	-	+	+	+	+	+	+
	b. Insights into the risks of a species establishment in relevant biogeographical regions in the risk assessment area		+	-	+	-	-	+	+	-	-	-	+	+	-	+	+
	c. Insights into the risks of a species spread within relevant biogeographical regions in the risk assessment area		+	-	+	-	-	+	+	-	-	-	+	+	-	+	+
	2. The thorough assessment of those risks does not have to include a full range of simulations	■▲□	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
	a. Assessment of likely introduction, establishment and spread within a medium timeframe scenario (e.g. 30-50 years) with a clear explanation of the assumptions is provided.		-	-	-	-	-	+	-	-	-	+	-	-	-	-	-

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	3. The risks referred to in point (1) may, for example, be described in terms of ‘likelihood’ or ‘rate’.	□	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
Distribution	**Art 5(1) (e) description of the current distribution of the species, including whether the species is already present in the Union or in neighbouring countries, and a projection of its likely future distribution**		**1/2**	**1/2**	**1/2**	**2/2**	**2/2**	**2/2**	**1/2**	**1/2**	**1/2**	**1/2**	**1/2**	**2/2**	**2/2**	**1/2**	**2/2**
	1. The description of the current distribution in the risk assessment area or in neighbouring countries	▲□	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1
	2. The projection of the likely future distribution in the risk assessment area or in neighbouring countries	▲□	0	0	0	1	1	1	0	0	0	1	1	1	1	0	1
Impacts	**Art 5(1) (f) description of the adverse impact on biodiversity and related ecosystem services, including on native species, protected sites, endangered habitats, as well as on human health, safety, and the economy including an assessment of the potential future impact having regard to available scientific knowledge**		**4/5**	**3/5**	**5/5**	**3/5**	**4/5**	**5/5**	**3/5**	**4/5**	**2/5**	**4/5**	**4/5**	**4/5**	**3/5**	**4/5**	**3/5**

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	1. In the description, a distinction shall be made between the known impact and the potential future impact on biodiversity and related ecosystem services	▲□	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0
	a. Biodiversity		+	+	+	+	+	+	+	+	-	+	+	+	+	+	-
	b. Ecosystem services		-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	2. The description of the known impact and the assessment of the potential future impact. The magnitude of the impact. The impact scoring or classification system.	▲	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	a. The description of the known impact and the assessment of the potential future impact.		+	+	-	-	+	+	+	+	+	+	+	+	+	+	+
	b. The magnitude of the impact.		+	+	+	+	+	+	+	+	+	+	+	+	-	+	-
	c. The impact scoring or classification system.		+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
	3. The description of the known impact and the assessment of the potential future impact on biodiversity	▲□	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	a. The different biogeographic regions or marine subregions where the species could establish		+	+	+	+	+	+	-	-	-	+	+	+	+	+	+

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	b. Native species impacted, including red list species and species listed in the annexes of Council Directive 92/43/EEC (2) and species covered by Directive 2009/147/EC of the European Parliament and of the Council (3)		+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
	c. Habitats impacted, including red list habitats and habitats listed in the annexes of Directive 92/43/EEC		-	+	+	+	+	+	+	+	+	+	+	+	+	-	+
	d. Protected sites impacted		-	-	+	+	-	+	+	+	+	+	+	+	-	+	+
	e. Impacted chemical, physical or structural characteristics and functioning of ecosystems		+	+	-	-	-	+	-	+	+	+	+	+	-	+	-
	f. Impacted ecological status of aquatic ecosystems or impacted environmental status of marine waters		-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
	4. The description of the known impact and the assessment of the potential future impact on related ecosystem services		0	0	1	0	1	1	0	0	0	0	0	0	0	0	0

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	a. Provisioning services		-	-	+	-	-	+	-	-	-	-	-	-	-	-	-
	b. Regulating services,		-	-	+	-	+	+	-	-	-	-	-	-	-	-	-
	c. Cultural services		-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	5. The description of the known impact and the assessment of potential future impact on human health, safety and the economy	▲□	1	0	1	0	1	1	0	1	0	1	1	1	0	1	1
	a. Human health - illnesses, allergies or other affections to humans that may derive directly or indirectly from a species,		+	-	-	-	+	+	-	+	-	+	+	+	-	+	+
	b. Human safety - damages provoked directly or indirectly by a species with consequences for the safety of people, property or infrastructure		+	-	-	-	+	+	-	+	-	+	+	+	-	+	+
	c. Economy - direct or indirect disruption of, or other consequences for, an economic or social activity due to the presence of a specie		+	-	+	-	+	+	-	+	-	-	+	+	-	+	+
Potential costs of damage	**Art 5(1)(g) - an assessment of the potential costs of damage**		**0/2**	**0/2**	**0/2**	**0/2**	**0/2**	**1/2**	**1/2**	**0/2**	**0/2**	**0/2**	**0/2**	**2/2**	**0/2**	**2/2**	**0/2**

RA components	Common elements described in EU regulation supplement on RA of IAS (EU, 2018)	IMO RA approach type	Bioinvasion risk and impact assessment methods														
			AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMO-NIA+	TRAAIS	SBRA	GLOTSS	WISC	RABW
	1. The assessment, in monetary or other terms, of the potential costs of damage on biodiversity and ecosystem services		0	0	0	0	0	1	1	0	0	0	0	1	0	1	0
	2. The assessment of the potential costs of damage on human health, safety, and the economy		0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Known uses and benefits	**Art 5(1)(h) - a description of the known uses for the species and social and economic benefits deriving from those uses**		**1/2**	**0/2**	**0/2**	**0/2**	**1/2**	**0/2**	**0/2**	**0/2**	**0/2**	**0/2**	**0/2**	**2/2**	**0/2**	**0/2**	**0/2**
	1. The description of known uses for the species		1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	2. The description of social and economic benefits deriving from the known uses for the species		0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Total number of RA elements considered in the method/ Total number of RA elements			**21/29**	**11/29**	**20/29**	**15/29**	**22/29**	**24/29**	**16/29**	**11/29**	**12/29**	**23/29**	**21/29**	**26/29**	**17/29**	**22/29**	**21/29**
Total coverage (%)			**72**	**38**	**69**	**52**	**76**	**83**	**55**	**38**	**41**	**79**	**72**	**90**	**59**	**76**	**72**

Annex 4. **Screening results for categories of impact types covered in method**

Impact types Categories	Bioinvasion risk and impact assessment methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	TRAAIS	GLOTSS	WISC	SBRA	RABW
Social and cultural	**2/4**	**0/4**	**1/4**	**1/4**	**0/4**	**1/4**	**0/4**	**2/4**	**0/4**	**0/4**	**2/4**	**1/4**	**2/4**	**3/4**	**0/4**
Recreation and tourism locations	1	0	1	1	0	1	0	1	0	0	1	0	1	1	0
Education and research	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0
Spiritual and religious locations	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Interference with monitoring	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Economical	**5/11**	**0/11**	**1/11**	**0/11**	**6/11**	**4/11**	**0/11**	**7/11**	**0/11**	**4/11**	**3/11**	**4/11**	**5/11**	**7/11**	**1/11**
General management costs	1	0	1	0	0	1	0	1	0	0	1	1	1	1	1
Fisheries	1	0	0	0	1	0	0	1	0	0	1	0	1	1	0
Aquaculture	1	0	0	0	1	0	0	1	0	0	1	1	1	1	0
Changes to wildlife habitat	1	0	0	0	1	1	0	1	0	0	0	0	1	0	0
Cost of changes to environment	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0
Irrigation and abstraction	0	0	0	0	1	0	0	1	0	1	0	1	1	1	0
Navigation	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0
Tourism	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0

Impact types Categories	Bioinvasion risk and impact assessment methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	TRAAIS	GLOTSS	WISC	SBRA	RABW
Health care costs	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Biotechnology	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Opportunity costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Environment	**12/20**	**13/20**	**10/20**	**7/20**	**12/20**	**10/20**	**9/20**	**18/20**	**12/20**	**12/20**	**16/20**	**9/20**	**7/20**	**15/20**	**4/20**
Parasite on native species	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
Predation	1	1	1	1	1	1	0	1	1	1	1	0	0	1	0
Hybridization	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0
Parasite vector	1	1	0	1	1	1	1	1	0	1	1	0	0	1	0
Habitat change or loss	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0
Competition	1	1	1	1	1	0	0	1	1	1	1	1	0	1	0
Pathogen on native species	0	1	0	0	1	1	1	1	1	1	1	0	0	1	1
Food web changes	1	1	1	0	1	0	0	1	1	1	1	1	0	1	0
Nutrient regime alterations	1	1	0	0	1	1	0	1	1	1	1	1	0	1	0
Biodiversity alteration	0	1	1	0	1	1	0	1	0	0	1	1	1	1	0
Pathogen vector	0	0	0	0	1	1	1	1	0	1	1	0	0	1	0
Herbivory/grazing	0	0	1	0	1	0	0	1	1	1	1	0	0	1	0
General ecosystem services	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0

Impact types Categories	Bioinvasion risk and impact assessment methods														
	AS-ISK	BINPAS	CIMPAL	CMIST	GABLIS	GB NNRA	GEIAA	GISS	GISS IUCN	HARMONIA+	TRAAIS	GLOTSS	WISC	SBRA	RABW
Keystone species	0	1	1	0	0	0	1	0	0	1	1	1	1	0	0
Threatened or endangered species	1	0	0	0	0	0	1	1	0	1	1	1	1	0	0
Toxicity on native species	0	1	1	0	0	0	0	1	1	0	0	0	0	1	0
Species abundance	0	1	1	0	0	0	1	1	0	0	0	1	1	1	0
Pest vector	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0
Pest on native species	1	0	0	0	0	0	0	1	0	0	1	0	0	1	1
Hydrological cycle changes	0	0	0	0	1	0	0	0	1	0	0	1	1	0	1
Human health	**2/6**	**0/6**	**1/6**	**0/6**	**3/6**	**3/6**	**0/6**	**6/6**	**0/6**	**3/6**	**2/6**	**0/6**	**3/6**	**4/6**	**1/6**
Human pathogen	0	0	0	0	1	1	0	1	0	1	1	0	0	1	0
Human parasites	0	0	0	0	1	1	0	1	0	1	1	0	0	0	0
General impact	1	0	0	0	1	1	0	1	0	1	0	0	1	1	1
Toxic to human	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0
Poisoning to human	1	0	0	0	0	0	0	1	0	0	0	0	1	1	0
Venomous organisms	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0

Annex 5. **New arrivals of non-indigenous species to the recipient regions of the Baltic Sea (DK – Denmark, SE – Sweden, FI – Finland, RU_S – Russia/Sankt-Petersburg area, EST – Estonia, LV – Latvia, LT – Lithuania, RU_K – Russia/Kaliningrad area, PL – Poland, GER – Germany) since 2000. Year of the primary introduction indicates: bold underlined - new for the Baltic Sea and the North Sea (L3); underlined - new for the Baltic Sea (L2); unformatted text – new for a recipient region (L1); (in brackets) – recorded before the assessment period. Pathway (Cult - Culture activities, Nat - Natural spread from neighboring countries, Vess – Vessels) and the level of certainty (*** Direct evidence, ** Very likely, * Possible) are indicated only for the highest level of primary introduction. N.d. – no data known for pathway.**

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Annelida	*Ficopomatus enigmaticus*	(1953)	2013								2014	Nat, Vess*
Annelida	*Boccardiella ligerica*		2013				2014				(1932)	Vess*
Annelida	*Hypania invalida*									2010	2010	Vess**
Annelida	*Laonome sp.*		2014			**2012**	2014			2015		Vess*
Annelida	*Limnodrilus cervix*									2010		Vess*
Annelida	*Marenzelleria viridis**	2001	(1996-2005)					2010			(1985)	Nat, Vess*
Annelida	*Marenzelleria arctia*		**2004**		2009							Nat, Vess*
Annelida	*Paranais frici*			2000-2008	**(1960-1969)**				(1998)			n.d.
Annelida	*Potamothrix hammoniensis*									**2010**		n.d.
Annelida	*Potamothrix moldaviensis*				(1950-1959)				(1996)	2008	2015	Nat, Vess*
Annelida	*Potamothrix vejdovskyi*		(1967-1970)		(1960-1969)				(1997)	2008		Nat, Vess
Annelida	*Tharyx killariensis*	2012										n.d.
Arthropoda	*Echinogammarus trichiatus*										2014	Nat**

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Arthropoda	*Evadne anonyx*		2008	(1998)	2000	(1999)	2000-2001		2007	2006	2014	Nat, Vessels*
Arthropoda	*Eurytemora carolleeae*										**<u>2012</u>**	n.d.
Arthropoda	*Gammarus tigrinus*		2000-2010	2003	2005	2006	2010	2004	(1999)	(1988)	(1975)	Nat, Vess*
Arthropoda	*Grandidierella japonica*		<u>2010</u>								2015	Nat, Vess**
Arthropoda	*Hemigrapsus takanoi*										<u>2014</u>	Nat**
Arthropoda	*Hemimysis anomala**		(1995)	(1992)	(1992)	(2009)		(1962)	(1962)	2002	1990-2015	Cult, Vess*
Arthropoda	*Homarus americanus*	<u>2007</u>									2014	F Tr**
Arthropoda	*Limnomysis benedeni*						(1966)	(1962)	(1962)		2010	Nat**
Arthropoda	*Melita nitida*									2014	<u>2010</u>	Vess*
Arthropoda	*Palaemon macrodactylus*									2014	(2009)	Nat, Vess*
Arthropoda	*Palaemon longirostris*									2018	(1999)	n.d.
Arthropoda	*Palaemon elegans*	(1995)		2003		2011	2009		2000-2002	2002	(1989)	Nat*
Arthropoda	*Paramysis (Serrapalpisis) lacustris*						(1966)	(1962)	(1962)		2013	Nat**
Arthropoda	*Paramysis (Mesomysis) intermedia*					**<u>2008</u>**			**<u>2008</u>**			Vess**
Arthropoda	*Pacifastacus leniusculus*					**<u>2014</u>**						Nat**
Arthropoda	*Proasellus coxalis*										<u>2011</u>	Cult, Vess*

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Arthropoda	*Penilia avirostris*	2001									2003	Nat, Vess*
Arthropoda	*Platorchestia platensis*	<1900	(1930-1940)							2005	(1940)	Nat*
Arthropoda	*Pontogammarus robustoides*				(1999)	2006	(1966)	(1962)	(1962-1963)	(1988)	(1994)	n.d.
Arthropoda	*Pseudocuma (Stenocuma) graciloides*								**2004**			Vess*
Arthropoda	*Rhithropanopeus harrisii*	(1953)	2014	2009		2011	2013	2001	(1950)	(1951)	(1948-1950)	Nat, Vess*
Arthropoda	*Sinelobus stanfordi*						2015				2012	Cult, Nat, Vess*
Arthropoda	*Sinelobus vanhaareni*			2016		2010				2014	2012	Nat, Vess*
Arthropoda	*Callinectes sapidus*	(1951)								2018		n.d.
Arthropoda	*Chelicorophium robustum*									2018		n.d.
Arthropoda	*Cercopagis (Cercopagis) pengoi**		(1995)	(1992)	(1995)	(1992)	(1992)	(1999)	(1999)	(1999)	2004	Nat**
Arthropoda	*Cornigerius maeoticus*				**2003**							Other canals**
Arthropoda	*Dikerogammarus villosus**						2015	2015		2002	1990-2015	Nat, Vess*
Arthropoda	*Jassa marmorata*										2010	Nat, Vess*
Arthropoda	*Orconectes limosus*						2006	(1994)		(<1900)	(1990-2015)	Nat*
Arthropoda	*Telmatogeton japonicus*		2007	2008						(1972)	(1962)	Nat, Vess*

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Acantho-cephala	*Paratenuisentis ambiguus*								2004	2001		Nat, Vess*
Chlorophyta	*Chara connivens*		(1930-1950)	2004		(1930-1959)	(1930-1950)			(1900-1907)	(<1900)	n.d.
Chordata	*Styela clava*										2017	n.d.
Chordata	*Acipenser gueldenstaedtii*	2013	(1966)	2000	(1964-1966)	(1962-1969)	(1962)			(1985)	(1990-1999)	Cult*
Chordata	*Neogobius melanostomus**	2008	2008	2005	2012	2002	2004	2002	2000	(1990)	(1999)	Vess*
Chordata	*Carassius gibelio*		(<1997)	2001-2005	2005	(1948)	(1948)	*<1700*		(1930-1933)		Nat*
Chordata	*Hypophthalmichthys nobilis*					**2002**	**2002**					Cult**
Chordata	*Huso huso*	2010				(1962)	(1962)					n.d. / Cult***
Chordata	*Proterorhinus marmoratus*				**2006**							Other canals*
Chordata	*Ictalurus punctatus*					**2001**						Cult**
Cnidaria	*Diadumene lineata*										2011	Vess***
Cnidaria	*Garveia franciscana*										2014	n.d.
Cnidaria	*Maeotias marginata*			2012		(1999)						
Cnidaria	*Moerisia inkermanica*										2018	n.d.
Cnidaria	*Blackfordia virginica*										2014	Vess*
Ctenophora	*Beroe ovata*	**2011**										Nat, Vess*
Ctenophora	*Mnemiopsis leidyi*	2007	2006						2007	2007	2006	Nat, Vess*
Mollusca	*Dreissena bugensis*				2004					(2011)	2015	Nat, Vess*

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Mollusca	*Dreissena polymorpha**		2012 (2008)	(1995)	(1970-1980)	(<1900)	(<1900)	(<1900)	(<1900)	(<1900)	(<1900)	Vess*
Mollusca	*Mytilopsis leucophaeata*		2011	2003			2015			2010	(1928)	Nat, Vess*
Mollusca	*Rangia cuneata**		2016			2014		2013	2010	2011	2014-2015	Vess**
Mollusca	*Haminoea solitaria*										**2016**	n.d.
Myzozoa	*Peridinium quinquecorne*		2008									Vess*
Myzozoa	*Prorocentrum cordatum*	(1982)	(1982)	(1993)	2000-2010	(1997)	(1988)	(1992)	2010	(1989)	(1982)	Nat, Vess*
Rhodophyta	*Antithamnionella ternifolia*										2014	
Rhodophyta	*Dasya baillouviana*	(1961)									2002	Cult, Nat, Vess*
Rhodophyta	*Gracilaria vermiculophylla*	2003									2005	Cult, Nat, Ves*
Ochrophyta	*Chaetoceros cf. lorenzianus**							2005		**2003**	2009	Nat*
Ochrophyta	*Lennoxia faveolata*	2009	2007								2009	Cult, Nat, Vess*
Platyhelminthes	*Pseudodactylogyrus anguillae*	(1985)							2002	(1985)		Cult, Nat*

Phylum	Species	Recipient region*										Pathway
		DK	SE	FI	RU_S	EST	LV	LT	RU_K	PL	GER	
Tracheophyta	*Spartina townsendii var. anglica*	2000-2006										Nat*
		DK	**SE**	**FI**	**RU_S**	**EST**	**LV**	**LT**	**RU_K**	**PL**	**GER**	
2010-2018	**N-NIS L1**	**4**	**7**	**2**	**1**	**6**	**7**	**3**	**2**	**13**	**24**	
	N-NIS L2	**2**	**1**	**0**	**0**	**3**	**0**	**0**	**1**	**4**	**14**	
	N-NIS L3	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**1**	**2**	
2000-2009	**N-NIS L1**	**8**	**10**	**10**	**8**	**7**	**5**	**4**	**8**	**10**	**9**	
	N-NIS L2	**4**	**4**	**0**	**3**	**3**	**1**	**0**	**2**	**2**	**1**	
	N-NIS L3	**0**	**1**	**0**	**2**	**3**	**1**	**0**	**2**	**1**	**1**	

Annex 6.

Country/country region	*Coastline (km)**	*Number of ports*	*Ports with container liner service*	*Monitoring stations (HELCOM)*	*Salinity range, PSU*	*Average temperature range, °C*	*Reference*
Denmark	4605	159	4	17	9.6 - 30.2	2 - 16	Dargahi et al. 2017; Snoeijs-Leijonmalm et al. 2017; HELCOM 2018;
Sweden	3218	82	9	22	1.2 - 6.6	0 - 17	
Finland	1250	60	5	17	1.2 - 6.6	0 - 17	
Russia/St. Petersburg	820	7	2	11	1.2 - 5.6	0 - 17	
Germany	2100	3	5	27	7.6 - 22.9	2 - 18	
Estonia	3794	26	1	7	4.1 - 7.5	0 - 18	
Latvia	531	6	1	10	4.1 - 6.2	0 - 18	
Lithuania	90	1	1	4	5.0 - 7.5	1 - 16	
Russia/Kaliningrad dist.	145	1	1	0	5.0 - 7.5	1 - 16	
Poland	440	12	2	17	5.0 - 7.5	2 - 18	

Annex 7. **The list of species and additional data which was used to count expansion rate for invasion potential subcategory.**

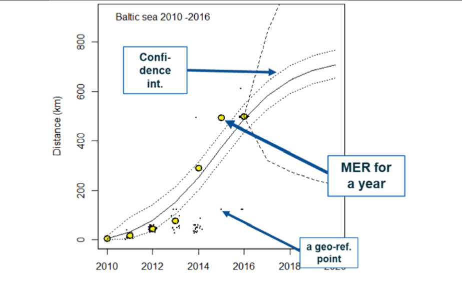
No.	Species name	Latin name	Number of years	Number of observations	Expansion rate (km/year)	Invasion potential subcategory	Pelagic stage (yes/no)	Salinity range	Reference/ link
1	Bloody-red shrimp (marine)	*Hemimysis anomala*	6	11	168.7	High	No	0-18	https://www.cabi.org/isc/datasheet/108015
2	Clam (brackish)	*Rangia cuneata*	6	159	133.0	High	Yes/ partly	0-18	https://www.fws.gov/fisheries/ans/erss/uncertainrisk/Rangia-cuneata-WEB-10-01-12.pdf
3	Fishhook waterflea (marine, brackish, fresh)	*Cercopagis (Cercopagis) pengoi*	5	108	102.9	High	No	0-17	https://www.fws.gov/fisheries/ANS/erss/highrisk/ERSS-Cercopagis-pengoi-Nov-2017-FINAL.pdf
4	Polychaete (marine, fresh)	*Marenzelleria viridis*	21	392	79.2	High	Yes/ partly	1-32	Bochert 1997
5	Diatom (marine)	*Chaetoceros cf. lorenzianus*	4	6	62.7	High	Yes	0.5-40	Elliott and Ducrotoy 1991
6	Zebra mussel (brackish, fresh)	*Dreissena polymorpha*	8	30	60.7	High	Yes	0- 6	Kilgour et al. 1994

No.	Species name	Latin name	Number of years	Number of observations	Expansion rate (km/ year)	Invasion potential subcategory	Pelagic stage (yes/no)	Salinity range	Reference/ link
7	Round goby (marine, brackish, fresh)	*Neogobius melanostomus*	21	333	52.8	High	Yes/ partly	0-25	Behrens et al. 2015
8	Prussian carp (brackish)	*Carassius gibelio*	5	6	10.6	Moderate	Yes/ partly	0-15	Schofield, et al. 2006
9	Killer shrimp (brackish, fresh)	*Dikerogamma-rus villosus*	4	10	3.6	Restricted	No	0-12	https://www.cabi.org/isc/datasheet/108309
10	Australian tubeworm (marine, brackish, fresh)	*Ficopomatus enigmaticus*	4	4	2.6	Restricted	Yes/ partly	10-30	https://www.cabi.org/isc/datasheet/108338

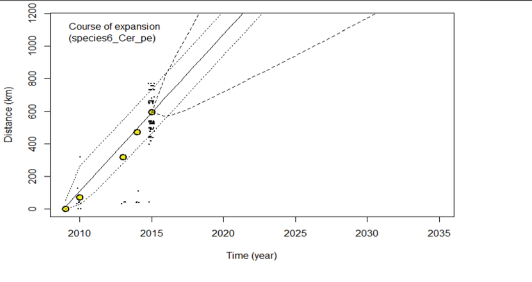
Annex 8. **Occurences of NIS species, data used for MER calculations.**

	Phylum	*Class*	*Species*	*Geo-reference data*			*Total points*
				Exact coordinates (ICES; other)	*Map digitalisation*	*Expert judgement*	
1	*Chordata*	*Actinopterygii*	*Carassius gibelio*	*3*	*1*	*2*	*6*
2	*Arthropoda*	*Branchiopoda*	*Cercopagis (Cercopagis) pengoi*	*108*	*-*	*-*	*108*
3	*Ochrophyta*	*Coscinodiscophyceae*	*Chaetoceros cf. lorenzianus*	*-*	*5*	*1*	*6*
4	*Arthropoda*	*Malacostraca*	*Dikerogammarus villosus*	*4*	*10*	*-*	*14*
5	*Mollusca*	*Bivalvia*	*Dreissena polymorpha*	*30*	*-*	*-*	*30*
6	*Annelida*	*Polychaeta*	*Ficopomatus enigmaticus*	*-*	*-*	*4*	*4*
7	*Arthropoda*	*Malacostraca*	*Hemimysis anomala*	*1*	*5*	*5*	*11*
8	*Annelida*	*Polychaeta*	*Marenzelleria viridis*	*383*	*10*	*-*	*392*
9	*Chordata*	*Actinopterygii*	*Neogobius melanostomus*	*65*	*-*	*333*	*398*
10	*Mollusca*	*Bivalvia*	*Rangia cuneata*	*126*	*203*	*4*	*333*

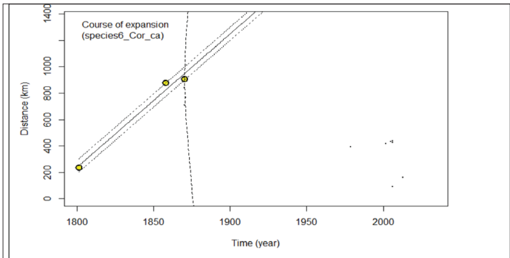
Annex 9. **Linear regression model of spread with regression line and 95% confidence intervals for selected 10 non-indigenous species in the Baltic sea region. Confidence int. – confidence interval; MER for a year – mean expansion rate counted for a year; a geo-ref. point – georeferenced point for each occurrence of the species.**



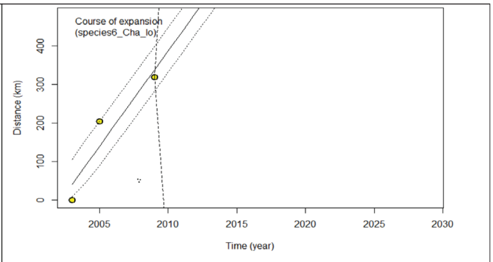
Rangia cuneata



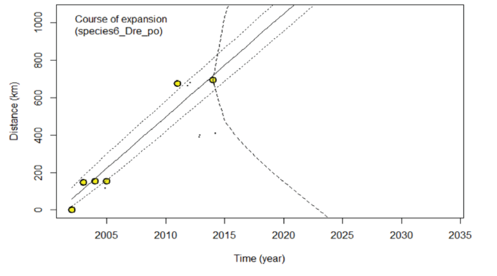
Cercopagis pengoi



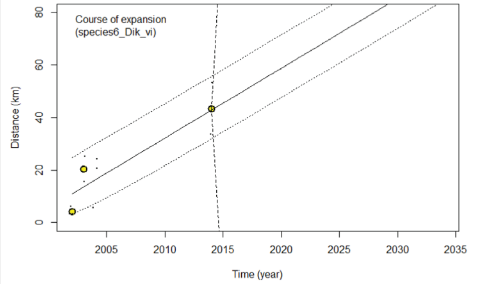
Cordylophora caspia



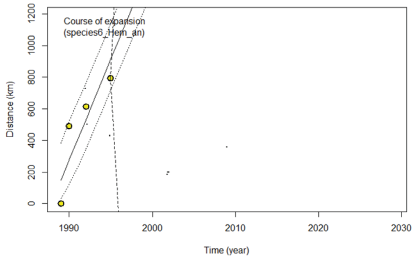
Chaetoceros cf. lorenzianus



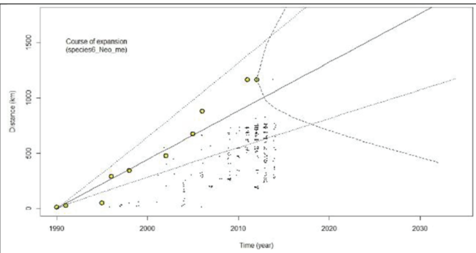
Dreissena polymorpha



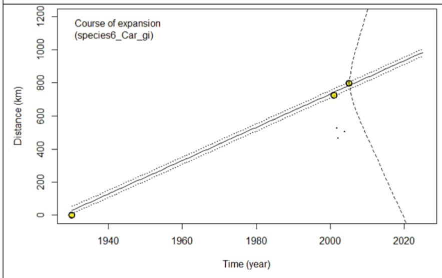
Dikerogammarus villosus



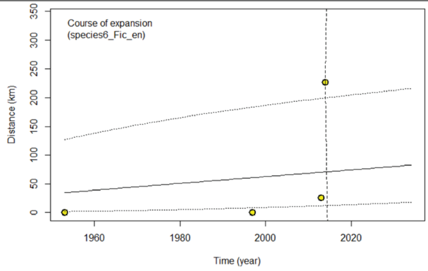
Hemimysis anomala



Neogobius melanostomus



Carassius gibelio



Ficopomaticus engimaticus

Klaipėdos universiteto leidykla

Greta Srėbalienė
QUANTITATIVE ASSESSMENT OF BIOINVASION IMPACTS ON MARINE ECOSYSTEMS
Doctoral dissertation

BIOLOGINIŲ INVAZIJŲ POVEIKIO JŪRŲ EKOSISTEMOMS KIEKYBINIS VERTINIMAS
Daktaro disertacija

Klaipėda, 2019

SL 1335. 2019 09 10. Apimtis 14,34 sąl. sp. l. Tiražas 40 egz.
Išleido ir spausdino Klaipėdos universiteto leidykla, Herkaus Manto g. 84, 92294 Klaipėda
Tel. (8 46) 398 891, el. paštas: leidykla@ku.lt; interneto adresas: http://www.ku.lt/leidykla/