Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

Mari Nord Myklebust

Developing a characterization factor and effect factor model for impacts of marine invasive species

Within the context of Life Cycle Impact Assessment

Master's thesis in Industrial Ecology
Supervisor: Francesca Verones
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Abstract

Marine species are increasingly transported and released to new habitats where they are alien. The impacts of alien species turning invasive are a growing concern. Assessing non-native invasive species in terms of their impact is thus essential for progress in ecology, but there is not yet established any standard, transparent way to quantify alien species invasiveness. However, life cycle assessment (LCA) is a method for environmental assessments and management, which allows for quantitative decision support. The method aims to identify strategies for environmental improvements without problem shifting. The present thesis assesses marine invasive species impact pathways, and investigates which pathways is the most relevant for further development, for the development of an operational effect factor within the framework of LCA and life cycle impact assessment (LCIA). The aim is to develop an operational effect factor model, and if possible, a characterization factor for marine invasive species.

Marine invasive species introductions through ballast water showed to be an important vector of alien species introductions in the present thesis. Ballast water is thus recognized herein to represent the total number of alien species introduced in ecoregion j. The impact pathway of alien species is defined thereafter and shows the link between inventory data; ballast water discharged in an ecoregion j, to; introduction of alien species through ballast water, to; the impact these species mediate in ecoregion j, and to; an indicator of ecosystem damage. The present thesis presents a preliminary characterization factor model based on this impact pathway, which represents the potentially affected fraction of species (PAF) per m^3 ballast water discharged in ecoregion j. The characterization factor includes a fate factor (FF), exposure factor (XF) and a complete operational effect factor (EF). The EF model constitutes the potentially affected fraction of species in region j due to the total impact mediated in the region. In other words, PAF per unit of stressor intensity. The level of influence of the invading species is estimated using a scoring system developed in the pre-project for the current thesis, these scores are summed to represent the toal impact mediated.

Characterization factors and effect factors are in this thesis calculated in a case study for South Norway and Northern Norway. Only the marine invasive species groups available in the Marine Life was included in the calculations, brackish and freshwater species was excluded. Data needed to calculate CF and EF was collected via the Marine Life database. However, ballast water discharges in an ecoregion is not available to date and was for the present thesis estimated by studying the shipping traffic and vessels types entering the region of study, as well as relevant studies of shipping transport and ballast water discharges. The CF are thus not corresponding actual true values..The preliminary CF for Southern Norway is 9,30E-13 PAF/m^3, and the CF of Northern Norway is 6.23E-11 PAF/m^3. While the EF are 2,77E-3 PAF and 4,76E-4 PAF accordingly.

Sammendrag

Marine arter blir stadig mer transportert og frigjort til nye habitater hvor de ikke er innfødte. Virkningen av fremmede arter som blir invaderende, er av voksende bekymring. Å kunne vurdere invaderende arters påvirkning på det marine miljø, er avgjørende for fremdriften i dagens økologi, men det er ennå ikke etablert noen standard helhetlig måte å kvantifisere slike fremmedlegemer på. Livsløpsanalyse (LCA) er imidlertid en metode for miljøvurdering og legger til rette for kvantitativ beslutningsstøtte, og metoden tar sikte på å identifisere strategier for miljøforbedringer uten problemskifte. Denne avhandlingen vurderer de ulike vektorene og prosessene til hvordan fremendarter blir introdusert til nye habitat. Avhandlingen undersøker hvilken introduksjonsprosess som er mest relevante for videre utvikling, mot utviklingen av en operativ effektfaktormodell innenfor LCA rammverket. Hovedmålet er å utvikle en operativ effektfaktor modell og, om mulig, en karakteriseringsfaktor modell for marine fremmedarter.

Ballastvann viste seg å være en viktig og den største vektoren for introdukjson av fremmedarter, og representerer dermed i denne avhandlingen den eneste vektoren for introduksjon av fremmedarter i en marin region j. Vektoren kan da legge grunlaget for fremmedarters vei fra introduskjon til skade. Denne prossesen starter fra «inventory» av studiet, som er volum ballast vann utladet i en region j, som fører til; inntrodusjon av fremmede arter gjennom ballastvann, til; virkningen fremmedartene har i region j, og til slutt; en indikator for skade på økosystemet. Denne oppgaven presenterer en foreløpig karakteriseringsfaktor (CF) modell basert på den utledede prosesssveien, der indikatoren for økosystem skade er bestem av en PAF metrisk; potensielle berørte brøkdelen av arter i region j. Den endelige CF modellen representerer da; PAF per m^3 ballastvann i en region j. Modellen utviklet innholder en skjebnefaktor (FF), eksponeringsfaktor (XF) og en komplett operativ effektfaktor (EF). Effektfaktoren representerer den potensielle brøkdelen berørte arter i region j grunnet den totale påvirkningen formidlet i regionen. Med andre ord PAF per enhent stressor intensity. De invderende arters nivå av påvirkning er estimert ved å bruke et scoringssystem utviklet i forprosjektet for den nåværende avhandling.

Karrakteriseringsfaktorer og effektfaktorer er i denne avhandlingen beregnet i en case-studie for Sør – Norge og Nord – Norge. Bare de marine invaedrende artene som er tilgjengelige i Marine Life ble inkludert i beregningene, brakvanns - og ferskvannsarter ble utelukket. Data som var nødvendige for å beregne både CF og EF, ble samlet inn via «Marine Life» database. Derimot, utslipp av ballastvann er ikke tilgjengelig per dags dato og ble derfor estimert ved å studere ballast vann studier, skipsfartstrafikk og fartøystyper. De beregnede CF-og EF-resultatene for Sør-Norge er tilsavarende 9,30E-13 PAF / m^3 og 2,77E-3 PAF, og for Sør-Norge er de; 6.23E-11 PAF/ m^3 og 4,76E-4 PAF.

Acknowledgements

This Master Thesis is a presentation of my work conducted in the spring of 2019 as a part of my M.Sc. degree in Industrial Ecology at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU), Trondheim. The present work is a follow up of a project thesis carried out in the fall of 2018. The work has been challenging at times, but it has taught me a lot about marine invasive species impact, about working with large data sets, and the complexity of factor modelling within the LCIA framework.

I would like to give special thanks to my supervisors Francesca Verones and co-supervisor John Sebastian Woods for their helpful guidance and invaluable comments during this project. Their knowledge and expertise have been valuable for my motivation and the work performed. In addition, I want to thank Radek Lonka on his guidance and help on the Marine Life database.

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Abbreviations

BWM	The International Convention for the Control and Management of Ships' Ballast Water and Sediments
CF	Characterization factor
EF	Effect factor
FF	Fate factor
IMO	International Maritime Organization
MEOW	Marine Ecoregions of the World
MRGID	Marine Regions Geographic IDentifier
NN	Northern Norway
SN	Southern Norway (and Finnmark)
PAF	Potentially affected fraction of species
PDF	Potentially disappeared fraction of species
XF	Exposure factor

1 Introduction

1.1 Marine invasive species

Marine alien (non-native, invasive) species have become increasingly of interest to researchers in the past two decades (Figure **1.1**), not only because of their increasingly high introduction rates, but also their effect on native and native species (Galil et al., 2018). The introduction rates of alien species are a global, increasing concern. In addition, impacts from alien, or rather invasive, species are considered as one of the most difficult to reverse pressures (Weidema, 2000).

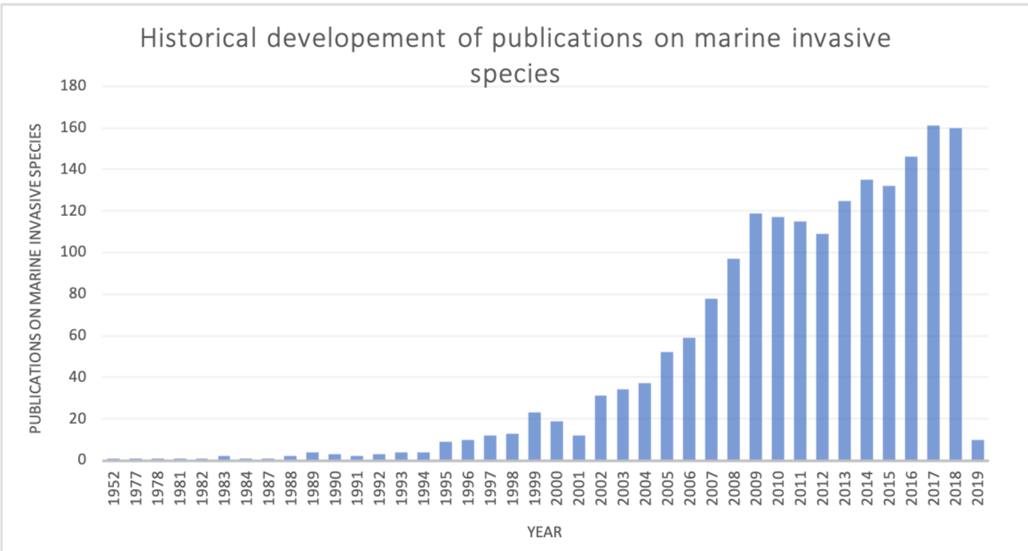


Figure 1.1: Historical development of peer-reviewed publications on marine invasive species in English language, based on data from Scopus (Search string in appendix 1).

Through increased global trade, tourism, aquaculture, and climate change, alien species find their way via different introduction pathways (via which species are introduced to, and spread widely within, a new region (Donaldson et al., 2014)) to foreign habitats outside their native ranges (Seebens et al., 2017). When first established in foreign habitats, alien species can rapidly spread and become invasive. While many alien species simply adapt and integrate into the native flora and fauna, others become invasive, reaching high densities and becoming dominant within the new habitat (Bax et al., 2003). Consequently, they endanger native species, modify habitats, change community structures, affect food web structures and ecosystem processes (Katsanevakis et al., 2014b, Catford et al., 2012). The impacts can also affect human health and cause substantial economic losses (Katsanevakis et al., 2014b). Interesting examples are the European green crab, *Carcinus maenas*, and the the pufferfish, *Lagocephalus sceleratus*. The european green crab is to be blamed for the collapse of bivalve fisheries on the North American east coast (Bax et al., 2003). The pufferfish, probably introduced through the

Suez Canal to the Mediterranean sea, has a strong neurotoxin (tetrodotoxi), and In worst case scenario the neurotoxin causes death due to respiratory paralysis if consumed. When the species arrived in the Mediterranean Sea, locals were unaware of the risks and couldn't identify the species, and incidents of poisoning occurred in Egypt, Israel and Lebanon (Bentur et al., 2008, Milazzo et al., 2012).

However, concerning the ecological impact, the European green crab, now found in Australia, Japan, South Africa and both coasts of North America, could potentially outcompete migratory bird populations for favoured shellfish on the west coast of North America (Bax et al., 2003). And The North Pacific sea star, *Asterias amurensis*,for instance; invaded Port Phillips Bay and reached over 100 million individuals covering 1500 km^2. The species has a greater biomass than all fished species in the bay area together, thus dominating native ranges in Port Phillips Bay (Bax et al., 2003). Another good example is the invasive zebra mussel, *Dreissena polymorpha*, that due to increased grazing was associated with an 85% decline in phytoplankton biomass in the Hudson River Estuary (Caraco et al., 1997). The research of Caraco et al. (1997) demonstrated that the zebra mussel actually caused this decline. Invasive species are therefore considered as important contributors to environmental change by many scientists, such as Bax et al. (2003), Dick et al. (2017), Galil et al. (2018), the Millennium Ecosystem Assessment (2001) and Pejchar et al. (2009).

The magnitude of the impact of different alien species is however hard to determine . It is rarely discussed how to decide whether the impact of one alien species exceeds that of another, or how to decide whether the impact of a particular alien species is greater in one place than in another (Parker et al., 1999). Catford et al. (2012) write that "alien species are considered invasive when they have established and managed to sustain self-replacing populations over several life cycles, reached large numbers, and spread a considerable distance from its site of introduction". However, this thesis follows the broader and more simple definition of invasive species by Molnar et al. (2008); an invasive species is a species reported to have established and causing impacts outside of its native range.

1.2 Life Cycle Assessment

To avoid neglecting environmental problems it it is important to have tools available for assessing the sustainability of the activities and processes in today's fast developing world of technology and services. Rutledge et al. (2011) write that "It is an old observation that what gets measured gets managed, and that what is not measured or measurable runs the risk of being neglected". Life cycle assessment (LCA) is a method for environmental assessments and management, which allows for such quantitative decision support. The method aims to identify strategies for environmental improvements without problem shifting (Hellweg et al., 2014).

Implementation of LCA in environmental management allows for quantifying potential environmental impacts of products, processes, or services. Rosenbaum (2018) stress that "the assessment method is meant to be used for comparative studies and facilitates the selection of environmentally preferable alternatives". The method also supports eco-design purposes and identification of the potentially largest environmental impacts and trade-offs in a product life cycle (Rosenbaum, 2018). LCA decisions have for these reasons come to be increasingly relevant for recognizing and reducing environmental impacts of both products and processes (Rosenbaum, 2018, Rutledge et al., 2011, Hellweg et al., 2014).

The LCA process typically occurs in four steps (Figure **1.2**). The first phase consists of defining the goal and scope of the assessment, and setting system boundaries and a functional unit. The second phase is the inventory analysis. This phase compiles inputs and outputs for each process in the life cycle and sums them across the whole system (Hellweg et al., 2014). In phase three, life cycle impact assessment (LCIA), emissions and resources are grouped according to their predefined impact categories and converted to common impact units to make them comparable. The final phase, aligning with answering the objectives of the study, aims to interpret the inventory and impact assessment results (Hellweg et al., 2014).

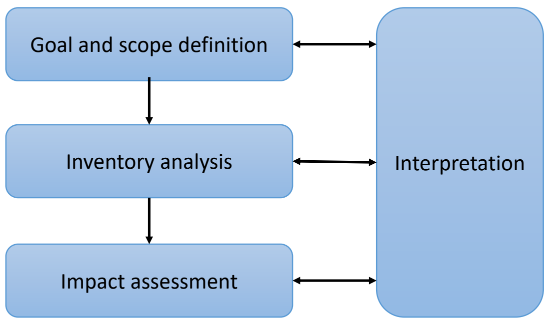


Figure 1.2: The steps of LCIA modified from Keoleian et al. (2006)

For this thesis, the LCIA phase is of most importance. LCIA allows for translating the inventory results into environmental impact scores, and aims to assess the magnitude of contribution of each elementary flow to an impact on the environment (Rosenbaum, 2018).

1.3 Objective and problem description

The attempts to measure invasive species impact and provide understanding of introduction pathways and impact, have dramatically increased over the past 20 years (Molnar et al., 2008, Bax et al., 2003, Dick et al., 2017, Dick et al., 2014). However, there is not yet established any standard, transparent way to quantify the damage to native species and habitats due to a certain degree of invasiveness (Catford et al., 2012, Katsanevakis et al., 2014b). Despite large advances in LCIA, only one preliminary approach exists for freshwater invasive species (Hanafiah et al., 2013), but nothing operational exists for marine invasive species. By generally researching marine invasive species and their impact pathways, the aim is to develop an operational effect factor and (if possible) a preliminary characterization factor within the LCIA framework. More specifically, the work amounts to:

1. Identify the most important and most promising impact pathway for further development for the development of a characterization factor (and if need be, make and defend restrictions on either geography or number of invasive species covered).
2. Integrate the scoring system developed in the master project into the Marine Life database that is being developed at the moment at the Industrial Ecology Program.
3. Based on task 1 and 2, come up with an operational effect factor (EF) for the selected region/species. If possible, define a potential "test" fate factor (FF), to come up with a full characterization (CF) factor for some regions.
4. Test the developed effect factor (or CF if possible) in a case study.

The present thesis will first give a deeper insight in the different vectors of introduction of marine alien species (chapter two) and describe impact pathways for further development, for the development of a characterization factor. A previous attempt from Hanafiah et al. (2013) on characterization factor modelling for freshwater invasive species is also presented. The latter is the only paper found on the topic of invasive species factor modelling within the context of LCIA. Further, chapter three contains general information on the Marine Life database which is under development by scientists at the Industrial Ecology Program of NTNU. Chapter three also describes a previously developed impact scoring system on marine invasive species by Myklebust (2018), and how the system could be integrated into the Marine Life database. Based on chapter two and three, the following chapter will contain characterization- and effect factor modeling. Chapter five presents a case study aiming to fulfill research question four in the objectives of the present thesis, and chapter six presents the results and discussion, followed by a conclusion in chapter seven.

2 Marine alien species introduction vectors

Translocation of marine species has, in the past decades, followed the growth of human activities driven by the modern globalized economy, and the introduction rate of marine alien species have increased accordingly (Bax et al., 2003). Bax et al. (2003) emphasize the high rate at which foreign species establish themselves in ports worldwide and write that a new estuarine and marine species has established once every 32 weeks to 85 weeks in six studied ports in the United States, Australia and New Zealand. At any given moment some 10 000 different species are being unintentionally transported between bio-geographic regions in ballast water alone (Bax et al., 2003). This chapter contains descriptions of the most relevant introduction vectors of marine alien species and presents the most promising impact pathway for further development of LCIA characterization and effect factors.

2.1 Introduction pathways and vectors

Molnar et al. (2008) report initial results from the first quantitative global assessment of alien species impacts and their vectors of introduction. Their initial analyses showed that only 16% of marine ecoregions have no reported marine invasions. They investigated 329 marine invasive species in total, including their distribution, impacts on biodiversity, and introduction pathways. More than 80 % of the assessed alien species were introduced unintentionally, and for 70 % of them the most common pathway was shipping. The aquaculture industry was the next most common introduction pathway for marine alien species (40 %), and the third most common was corridors through canal construction. The vectors of introduction are presented in Figure **2.1** below.

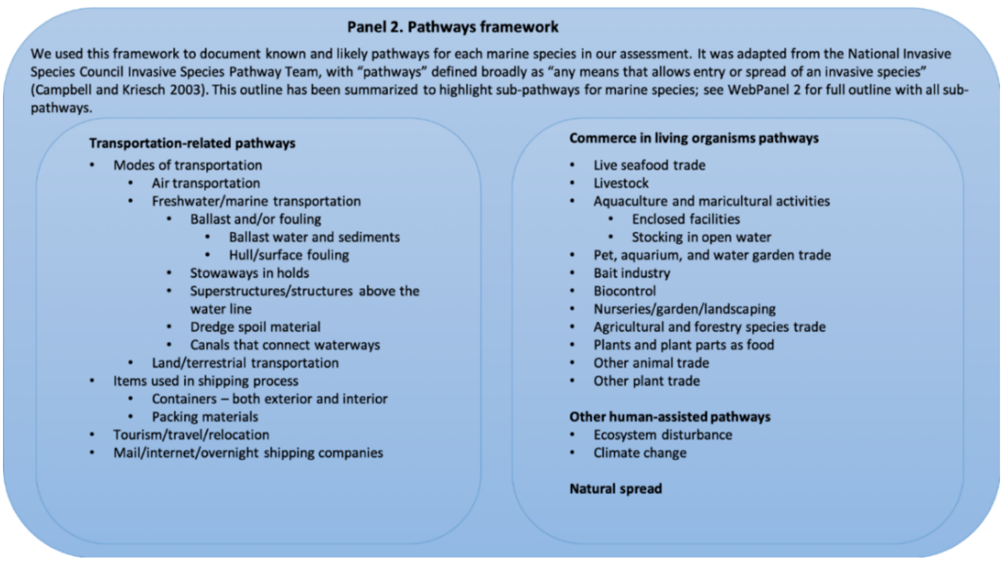


Figure 2.1: *Classification of introduction pathways for marine alien species (modified from Molnar et al. (2008)).*

Molnar et al. (2008) distinguish between four major pathways of introduction: 1) Transportation-related pathways; 2) Commerce in living organisms' pathways; 3) Other human-assisted pathways; and 4) Natural spread. The former three consist of various subcategories, labeled introduction vectors, such as hull fouling, ballast water, or stowaways (Molnar et al., 2008). Transportation-related pathways and aquaculture however, mainly represent accidental introductions, and pathways related to commerce in living organisms mainly cover intentional introductions (aquaria or as biocontrol-agents).

In contrast to Molnar et al. (2008) who concluded that corridors (canal constructions) is the third most common global pathway for marine species after shipping and aquaculture (41%), Katsanevakis et al. (2013) found that in Europe the situation differs from the global picture, with marine and inland corridors being the second most common pathway after shipping. This is primarily because of the Suez Canal and its role as a corridor for the movement of thermophilic species of Indo-Pacific origin into the Mediterranean Sea. The next most common vectors of introduction identified in their study are aquaculture and aquarium trade.

2.1.1 Shipping

Kaluza et al. (2010) stress that with 90 % of world trade transported by sea, the global network of merchant ships provides one of the most important modes of transportation of alien species. Species introduced by shipping initially get established in one or more locations, and they extend their range by natural dispersal and other vectors (Katsanevakis et al., 2013). Shipping is documented to be an important vector of marine alien species introductions, and to play an increasingly important role in anthropogenic movements of alien marine species due to the expanded trade and maritime traffic volume (Molnar et al., 2008, Katsanevakis et al., 2013, Ruiz et al., 1997, Ware et al., 2014, Kaluza et al., 2010, IMO, 2017). Introductions via shipping takes place mostly through hull fouling or through ballast water and sediments, or in some cases could have potentially unknown reasons. Due to the fact that marine shipping transport is currently playing the most important role in the introduction of marine alien species and is responsible for the largest proportion of alien species introductions in the marine environment, this vector is described in more detail than the other vectors.

Hull fouling

Hull fouling is described as «the undesirable accumulation of microorganisms, plants, algae and animals on submerged structures (especially ships' hulls)» (IMO, 2019c). Antifouling technology has evolved substantially, and the two main technologies commercially available today are biocidal antifouling paints and fouling release paints (Pagoropoulos et al., 2018). However, fouling often occurs and hull cleanings are still conducted to manage this problem with the overall aim to mitigate increased costs due to higher frictional drag from fouling (Pagoropoulos et al., 2018). During these hull cleanings marine organisms, such as algae, crustaceans, and slime, that have settled on the hull, are removed (Pagoropoulos et al., 2018). The cleanings conducted are mainly based on commercial considerations, as it is entirely up to the ship owner to decide when and where to perform a hull cleaning (in some cases, ship owners can be legally obliged to do so by the owners of the cargo) (Pagoropoulos et al., 2018).

Ballast water and sediments

When ships were first built, they carried solid ballast in the form of rocks, sand or metal (GloBallast, 2014). However, ever since the 1880s, ships have used water as ballast (GloBallast, 2014). GloBallast (2014) write that water is more readily available, much easier to load on and off a ship, and therefore more efficient and economic than solid ballast. But together with ballast water comes ballast sediments. The ballast water contains material, often turbid or solid material from shallow waters, that settles to the bottom as *sediment* and provides a substrate for a variety of marine species (notably dinoflagellates) (GloBallast, 2014). The international maritime organization (IMO) (IMO, 2019b) writes that:

> *"Ballast water may be taken onboard by ships for stability and can contain thousands of aquatic or marine microbes, plants and animals, which are then carried across the globe. Untreated ballast water released at the ship's destination could potentially introduce a new invasive marine species"* (**Figure 2.2**).

In line with researchers (Molnar et al., 2008, Katsanevakis et al., 2013, Ruiz et al., 1997, Ware et al., 2014, Bax et al., 2003, Kaluza et al., 2010) the IMO further emphasizes that hundreds of such invasions have already taken place, including bacteria, microbes, small invertebrates, algae, eggs, cysts and larvae of various species (IMO, 2019c).

Figure 2.2: Introduction of alien species through ballast water (IMO, 2019b).

GloBallast (2014) recognize ballast water as one of the principal vectors of potentially invasive alien species, and they have thus implemented The GloBallast project. The GloBallast project is a large-scale action taken by IMO together with other international entities, to reduce the associated negative impact of shipping on the marine ecosystems. The vector of introduction is estimated to be responsible for the transfer of between 7,000 and 10,000 different species of marine microbes, plants and animals globally each day (GloBallast, 2014). It is estimated that around 3-5 billion tons of ballast water is transferred globally each year with an individual ship, depending on the size and purpose of the ship, carrying anything from several hundred liters to more than 130,000 tons of ballast water (GloBallast, 2014).

2.1.2 Aquaculture

Aquaculture is the only vector for which the trend of new introductions substantially decreased during the previous decade (Katsanevakis et al., 2013).The vectors included are commodity and contaminant, were Katsanevakis et al. (2013) refers commodity to "all commercial species that were introduced to be cultured and includes both release and escape as it is often difficult to discern between the two", while contaminant is "species accidentally introduced together with imported target species"

Aquaculture is an introduction pathway that can be more effectively controlled than any other pathway, and during the last two decades administrators and policy makers started to recognize the need to apply rules to the aquaculture industry (Katsanevakis et al., 2013). Fixed and licensed locations, standard procedures, and implementation of an EU regulation, have contributed to a sharp decrease in the rate of new introductions, which fell to 17 species/decade from a maximum of 33 species/decade the last decade (Katsanevakis et al., 2013).

Katsanevakis et al. (2014a) document that aquaculture is considered responsible for 206 marine alien species introductions in the Mediterranean Sea, either as commodities or as contaminants of shellfish. Most of these introductions are being non-intentional, and two main hotspot areas were identified, the Thau lagoon (Gulf of Lion, France), and the Venice lagoon (Northern Adriatic, Italy) (Katsanevakis et al., 2014a). The same study describes that a frequent pattern of these invasions is that more than one site of introduction exists. The sites are colonized independently and are gradually expanding by natural processes. These independently expanding invaded areas might eventually merge into larger areas where the separate populations mix, and could potentially have a bigger impact on the environment than first anticipated when the sites were colonized independently (Katsanevakis et al., 2014a).

2.1.3 Introduction through corridors

The Suez Canal is expected to play an increasing role as an invasion pathway into the Mediterranean sea (Gallardo et al., 2016). Katsanevakis et al. (2013) classify typical introduction pathways for certain taxonomic groups, where fish are introduced through the Suez Canal, macrophytes mostly by aquaculture, and invertebrates through both the Suez Canal and by shipping. They further stress that "the high rate of new introductions through the Suez Canal is largely explained by the continuous modifications in the Canal and the surrounding environment during the last decades". Also worth to mention is the Panama Canal, which at present provides passage for approximately 38% of the trade between Asia and the East Coast of the United States (Craven et al., 2009). Gollasch et al. (2006) stress that one might expect establishments of many non-native species along the coast of Panama due to shipping, and that the canal has surely caused a shift in both species' composition and abundances.

2.1.4 Aquarium trade

Thousands of species are introduced to foreign habitats in terms of aquarium capture. They are kept under uncontrolled and often unsecure conditions, and are frequently released to the wild or disposed of improperly, finding their way to the marine or freshwater environment (Katsanevakis et al., 2013). Apart from species intentionally transferred by the aquarium trade, many other plant or invertebrate species are accidentally transferred as contaminants, associated with aquatic plants, rocks, sediments, or detritus (Katsanevakis et al., 2013). The introduction of aquarium species to non-native areas is a problem more acute for freshwater than for marine species (Katsanevakis et al., 2013). However, between 1.5 and 2 million people worldwide are believed to keep marine aquariums, and the numbers of traded marine species are estimated to be 24 million individuals of 1500 fish species, 12 million pieces of 140 species of stony corals, 10 million animals of 500 species of invertebrates (other than corals), and countless numbers of plants and taxa transported as contaminants (Katsanevakis et al., 2013).

Katsanevakis et al. (2013) stress that over the past decade, technical advances in captive care and life support system technologies have made marine aquaria more accessible to common households, thus increasing the demand for marine ornamental species. This again increases the number of marine ornamental species that are released to the sea, because of renovations or demolitions of the hobbyists' aquaria. The consequences are causing an increased propagule pressure and higher chances of successful establishments. The observed increasing rate of new introductions and associated risk posed through aquarium trade could, however, be reduced by enforcing similar regulations and procedures as to aquaculture (see section 2.1.2), and by raising awareness in the public about the dangers of releasing aquarium species to the sea or improperly disposing of aquarium water, rocks and sediments (Katsanevakis et al., 2013).

2.1.5 Ocean rafting

Anthropogenic plastic pollution is a global problem (Barnes et al., 2009, Derraik, 2002). However, one problem that has received less attention is the role of anthropogenic litter items serving as artificial rafts for marine alien species (Rech et al., 2018, Miller et al., 2018). In contrast to other known marine transport vectors of alien species, such as ship hull fouling and ballast water, introduction through ocean rafting on litter and plastic debris are less assessed (Rech et al., 2018, Miller et al., 2018). Rech et al. (2018) stress that to date, there is no clear understanding of the scale and the underlying processes of this phenomenon.

Rech et al. (2018) identify anthropogenic litter pollution as a factor to potentially double marine rafting opportunities. On some beaches, their study identified that 60% of all collected anthropogenic litter items carried attached organisms. The vast majority of these ocean rafting was on plastic debris, but there were also cases of macrobiotic rafting on glass, metal, and paper objects (Rech et al., 2018). An example is the invading coral, *Oculina patagonica*, commonly found on submerged metal objects (Rech et al., 2018), and the stony coral, *Favia fragum*, that had probably crossed the Atlantic Ocean from the

USA to the Netherlands on a metal gas cylinder (Rech et al., 2018). Another example of ocean rafting is the unexpected outcome of the tragic 2011 Great East Japan earthquake and ensuing tsunami. Many living species of algae, invertebrates, and fish were transported up to 6000 km on or associated with tsunami-related debris items (Miller et al., 2018). Based on morphological and genetic evidence in their study, the Mediterranean mussel, *Mytilus galloprovincialis*, was determined as one of the most common species arriving on Japanese Tsunami Marine Debris. In June 2012. Miller et al. (2018) collected a large dock in Oregon that was torn loose during the tsunami, with up to many thousands of individuals. Many thousands of mussels arriving on Japanese Tsunami Marine Debris were observed in good condition and capable of reproduction.

2.2 Impact Pathway: From introduction vectors to impact

Transportation related pathways via shipping include the most important vectors for introduction of alien species, both through hull fouling and ballast water (2.1.1). Minton et al. (2005), Molnar et al. (2008) and Ruiz et al. (2000) confirm earlier studies indicating transport via ballast water or hull-fouling as the most important vectors of alien invasions in European seas, as well as most other seas. Hence, shipping is focused on in this thesis, for the further development of LCIA effect factors.

2.2.1 Impact pathway to factor modelling: Reviewing a previous attempt

An impact pathway shows the link(s) between inventory data and ecosystem damage. There is to date only one published approach to incorporate invasive species impacts in LCIA; By focusing on alien freshwater fish species in relation to the transport of goods, Hanafiah et al. (2013) developed a method for assessing the environmental impacts of exotic freshwater species introduction. The characterization factor (CF) model quantifies the potentially disappeared fraction (PDF) of native freshwater species due to shipping related transport aggregated over time and water volume, expressed in units of PDF·m^3·yr per kg of transported goods. It includes a river basin specific fate factor (FF) with a river basin specific effect factor (EF) summed over all affected river basins (Equation 1).

$$CF = \sum_i FF_i \times EF_i = \sum_i \frac{\Delta ESFi}{\Delta TR} \times \frac{\Delta PDF_i}{\Delta ESF_i} \times V_i$$

Equation 1

The fate factor FF_i is the FF of river basin I, where ΔESF_i is the change of fraction of exotic freshwater species as part of the total species pool establishment in river basin i (exotic species), and ΔTR is the change in yearly transport of goods (kg·yr^{-1}). The effect factor is expressed as the potentially disappeared fraction (PDF) of native species multiplied by the river volume affected, per fraction of exotic species introduced (ESF). To be able to derive an effect factor an empirical stressor-response relationship between the fraction of exotic species introduced and the fraction of native species threatened was established. For this, the World Conservation Union (IUCN) Red List fish species was used as an approximation for the PDF of native fish species (Hanafiah et al., 2013). V_i in the EF is the volume of river basin i measured in volume of m^3.

However, their study has its limitations (Koslowski, 2017); First, a distinction between the level of impact of an invasive species is not undertaken, and a highly invasive species is thus treated equally as a less invasive species. Furthermore, a calculation on the contribution of regional reductions in species richness to global species reduction is not undertaken, meaning that regional impacts were not upscaled to a global level. And last, location specific impacts were entirely neglected as only the single value derivative of a linear regression was used for the fraction of ΔPDF by ΔESF for all examined watersheds.

2.2.2 Marine invasive species impact pathway

Based on the work presented in this chapter and the research of Hanafiah et al. (2013), an impact pathway on marine invasive species, introduced via shipping related transport, specifically ballast water, is developed in the present thesis. The impact pathway is illustrated in **Figure 2.3**. The indicator of ecosystem damage can be accounted by a PDF/PAF-based metric, where PDF/PAF stands for potentially disappeared/affected fraction of species (Frischknecht et al., 2016).

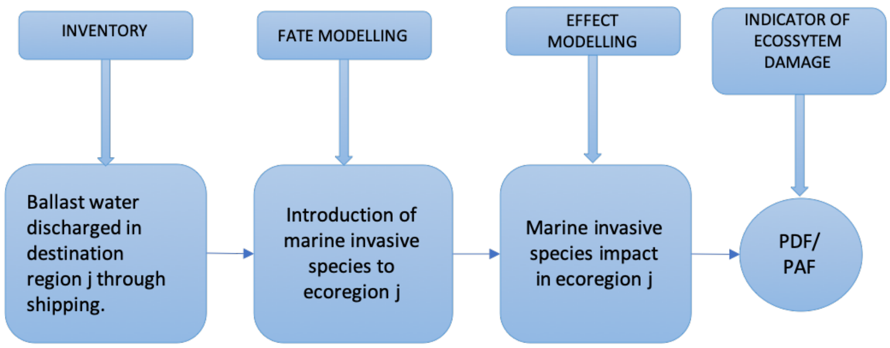


Figure 2.3: Impact pathway of marine invasive species to destination region j.

3 Marine Life Database and invasive species impact scoring system

3.1 The «Marine Life» database

A comprehensive database named "Marine Life" on marine alien species is under development at the Industrial Ecology (IndEcol) Program of NTNU. The final goal of developing the database is to list all marine alien species, including information on, among others, species taxonomies, introductions, and impacts, as well as assigning impact scores to each invasive species. After this thesis is concluded, both effect factors (and characterization factors) can potentially be calculated and added to the Marine Life database. The database is available at the NTNU IndEcol server. The platform used is Studio 3T (3T Software Labs GmbH, 2018) or MongoDB compass 1.16 (MongoDB, 2018). The credentials of connecting to the database can be collected through Radek Lonka, a Research Software Engineer at the Industrial Ecology Program, NTNU.

The Marine Life database comprises different collections containing both different and overlapping data on marine invasive species (screenshots of the collections in appendix 2). The collections are to be completely merged, which remains for future work. The main collections in Marine Life are (Koslowski, 2017):

1. World Register of Marine Species (WoRMS) (WoRMS Editorial Board, 2017)
2. Global Invasive Species Database (GISD) (Invasive Species Specialist Group ISSG, 2015)
3. Nature Conservancy database of marine invasive species (*NatCon*) (Molnar et al., 2008, The Nature Conservancy, 2017). This collection is also referred to as MOLNAR.

The overlap between these three collections follow a hierarchy, and since WoRMS contains most species, but not all, this is used as the dominant database. After that, GISD is added, and then *NatCon*. WoRMS lists marine alien species only, and include qualitative descriptions of their impact, as well as providing their non-native distribution statistics. GISD contains impact descriptions of marine invasive species and descriptions of both their native and alien ranges. *NatCon* includes alien species only and provides additional descriptions on invasive species distributions and impact.

3.2 Marine Life Map

A newer development of the Marine Life is ongoing to date by researchers at NTNU. This new version of the database facilitates for a distribution map of marine alien species. This version of Marine Life is implemented in Python 3.7.0 (Python, 2018) with use of Pandas 0.24 framework (Pandas, 2018). Ipython notebook (2019) is used as user interface to query, search and analyze results. For the present thesis the newest version of Marine Life is referred to as Marine Life Map. The credentials of connecting to the database can be collected through Radek Lonka, a Research Software Engineer at the Industrial Ecology Program, NTNU. The descriptions and further explanations of the database is also retrieved from Radek Lonka.

The marine ecoregions in the Marine Life Map are defined together with mapping of Marine Ecoregions of the World (MEOW) and Marine Regions Geographic IDentifier (MRGID), used in WoRMS. The marine ecoregions are served as entry points for a user. When the user selects ecoregions, OBIS API v3 (OBIS, 2017) is used to query all species in the ecoregion of choice. The code iterates over each species and finds occurrence from three sources, that is the three collections in Marine Life (WoRMS, GISD and NatCon/MOLNAR). Details of the three collections and how they are implemented in the Marine Life Map are described in Figure **3.1** below.

The Python module (IPython notebook) has two main objects. First, Marine Life ecoregions, which is created by using MEOW eco-code id. It contains information about all species in an ecoregion (observed/reported by OBIS) and information about which species are aliens and which species are affected by invasive species. Second, Marine Life species, which are used to store information about one species (created by selecting aphiaIDs) and contains information about alien and native occurrences.

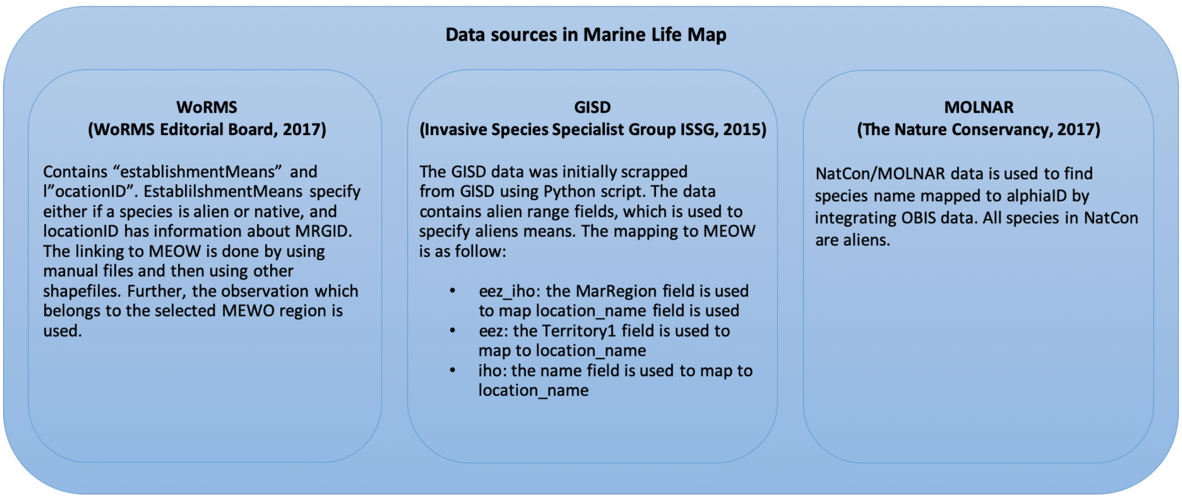


Figure 3.1: Implementation of data sources in Marine Life

3.3 Retrieving data in Marine Life

For the present thesis a case study (Chapter 5) was conducted where data from the Marine Life was collected. The data available and needed for the latter was invasive species impact descriptions, numbers on invasive species and numbers on affected species, for the ecoregions Southern Norway (SN) and Northern Norway and Finnmark, referred to as Northern Norway (NN) in the present thesis. Invasive species impact descriptions were needed to derive invasive species impact scores. Numbers on native species and affected/threatened species were needed together with the impact scores, to calculate EF and preliminary CF.

Extracting data from the old version of Marine Life was conducted manually in MongoDB Compass. The collections in MongoDB compass are organized and classified by; "src_worms_invasive" or "src_worms_all" (WoRMS), "src_gisd" (GISD), " 'src_molnar" *(NatCon)*, and "merge"; where all the mentioned collections are merged. These collections were used to retrieve impact descriptions on marine alien species. Numbers on native, alien and affected species, as well as the name of these species, can be found by using the Marine Life Map and associated IPython notebook (see section 3.2). However, the beta version of the Marine Life Map was used during the present thesis work, in retrospect, changes and updates may have occurred.

Retrieving data on marine invasive species impact descriptions

Impact descriptions can be extracted manually from WoRMS and GISD and NatCon in Marine Life database. Initial extractions of material were conducted in the "merged" collection by using the query string; {_id: "name of invasive species"}, for example; {_id: "Ciona intestinalis"}. In WoRMS the following query string was used; {scientificname: "name of invasive species"} and in GISD; {Species: "name of invasive species"}.

The Impact descriptions were extracted on Invasive species for Southern Norway and Northern Norway. All marine invasive species reported in the ecoregions of study are listed in Table **3.1**, and the scoring schemes and calculations are in appendix (appendix 3). The ecoregions of choice are selected on the foundation of available data.

Table 3.1: Invasive species in the ecoregions of study

Marine Alien species in the ecoregions of study

Alien species in Southern Norway	**Alien species in Northern Norway**
Ciona intestinalis	*Coscinodiscus wailesii*
Corethron criophilum	*Paralithodes camtschaticus*
Coscinodiscus wailesii	
Mya arenaria	
Rhizosolenia indica	
Salmacina dysteri	

Retrieving data on numbers of native and alien species

Numbers on alien species can be found by using the Marine Life Map associated with the Marine Life database (see section 3.2). The map uses data from the collections in Marine Life to represent alien species distributions by ecoregions. The native species numbers are a subtraction from the total number of species in the ecoregion of study.

Retrieving data on numbers of affected species

The data on marine species affected by invasive species is hosted by International Union for Conservation of Nature, IUCN (2019), red list of threatened species. The IUCN data on threatened species is essentially a checklist of taxa that have undergone an extinction risk assessment using the IUCN Red List Categories and Criteria. The numbers of affected species retrieved and used in the case study of the present thesis, are thus only species that are under the risk of extinction due to invasive species impact, hence threatened species.

3.4 Numerical scoring system of marine invasive species

A numerical scoring system of marine invasive species impact was developed during the project work of this thesis (Myklebust, 2018). This section is based on the latter, and the complete scoring system is presented in Figure **3.2** on next page.

It is important to have in mind that scoring systems are a tool to compare or rank variable data, but not an alternative to an empirical study directly measuring impact (Kumschick et al., 2015). The aim of the system is to translate the qualitative impact description of each species in the Marine Life database to quantitative threat scores which can further be developed and integrated in a characterization factor model for invasive species in an LCIA perspective. To score invasive species by the following system, impact descriptions are to be collected through the Marine Life Database (See section 3.3). For consistency, the impact scores are assigned globally for each species and reflect the most damaging documented impacts.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

A) GEOGRAPHIC EXTENT – 10 %

- **Geographic extent**
  4 – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  3 – Ecoregion - Established in no more than two adjoining ecoregions.
  2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  1 – Single site – single locality.
  0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

- **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**
  4 – Species has rapidly been introduced to areas of suitable habitat.
  3 – Species has less rapidly been introduced to areas of suitable habitat.
  2 – Species has regularly been introduced to areas of suitable habitat.
  1 – Species has seldom been introduced to areas of suitable habitat.
  0 – Unknown or not enough information to determine score.
- **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**
  4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  2 – Established/present, but not currently spreading.
  1 – Species has not spread/invaded once introduced.
  0 – Unknown or not enough information to determine score.
- **Propagule pressure criteria (The risks of transmitting genes or parasites).**
  4 – Documented events of both genes and parasites transmission.
  3 – Do cause either genes or parasites transmission to native species.
  2 – Possibility of transmitting parasites and genes to native species.
  1 – Minor possibility of transmitting genes and parasites
  0 – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

- **Population dynamic effects – in what grade do the alien species interact with native species.**
  4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  0 – Unknown or not enough information to determine score.
- **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**
  4 – Causing large scale changes by altering community structure
  3 – Cause medium to large documented impacts on community structure
  2 – Cause small to medium documented impacts on community structure
  1 – Causing minor impact on community structure
  0 – Unknown
- **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**
  4 – Causing large scale changes by altering ecosystem balance and functions
  3 – Cause medium to large documented impacts on ecosystem balance and functions
  2 – Cause small to medium documented impacts on ecosystem balance and functions
  1 – Causing minor impact on ecosystem balance and functions
  0 – Unknown or not enough information to determine score.

Figure 3.2: Scoring system of marine invasive species impact (Myklebust, 2018)

The scoring system considers three important factors (impact categories) of Impact, these are "Geographic Extent", "Invasive Potential", and "Ecological Impact". The system is necessarily semi- quantitative, but each impact score corresponds to categories that differ substantially in threat level, with clearly defined parameters for assigning individual scores. The scoring parameters in the present scoring system is inspired by Molnar et al. (2008)'s work. Each subcategory in the predefined impact categories include five criteria on level of impact, which correspond to quantitative scoring parameters that extend from 0-4, where 0 = Unknown or not enough information to determine score, and 4 is the highest level of impact for that given subcategory. Geographic Extent considers the non-native range of the alien invasive species only and contribute with a maximum score of 4. Invasive Potential considers both rate of spread, expansion rate and propagule pressure, each contributing with a maximum score of four. Thus, the total score for Invasive Potential can amount to a maximum score of 12. The same goes for Ecological Impact, where three sub categories exist: Population dynamic effects, Effects on ecosystem structure (degradation of water quality and/or physical habitat), and Effects on ecosystem balance and functions (Nutrient viability, primary productivity, resource pools and supply rates).

The system presented includes weighted attributes that sums up to 100 %, which reflects the total damage mediated from an alien species. The weighted attributes are of 10 %, 30 % and 60 %, corresponding the contribution of impact by the scores given in Geographic extent, Invasive potential and Ecological Impact. It is also possible to implement the system with both equal weighting or other weighted attributes than presented herein. The weighting presented herein are of value choice prioritizing environmental impacts and fair decision making in regard to equal species value. Different criteria and the choice of weighting attributes to each impact category are described in more details on next page. The total impact scores are to be calculated with Equation 2 below. These scores can be transferred to qualitative measurements by a scoring scale. This scoring scale expands from 0-1 (0 % -100%), which correspond to zero or low impact (0 % - 20 %) to Medium impact (20 % - 40 %), moderate impact (40 % - 60 %), high impact (60 % - 80 %), and very high impact (80 - 100 %).

$$\text{Total Score} = \frac{Score_{\text{Geographic Extent}}}{MAX_{\text{Geographic Extent}}} \times W_{\text{Geographic Extent}} + \frac{Score_{\text{Invasive Potential}}}{MAX_{\text{Invasive Potential}}} \times W_{\text{Invasive Potential}} + \frac{Score_{\text{Ecological Impact}}}{MAX_{\text{Ecological Impact}}} \times W_{\text{Ecological Impact}}$$

Equation 2

- Total Score = Total impact score of a chosen alien species
- $\text{Score}_{\text{Geographic Extent}}$ = Sum of impact scores in Geographic Extent
- $\text{Score}_{\text{Invasive Potential}}$ = Sum of impact scores in Invasive Potential
- $\text{Score}_{\text{Ecological Impact}}$ = Sum of impact scores in Ecological Impact
- $\text{MAX}_{\text{Geographic Extent}}$ = Maximum possible impact score in Geographic Extent
- $\text{MAX}_{\text{Invasive Potential}}$ = Maximum possible impact score in Invasive Potential
- $\text{MAX}_{\text{Ecological Impact}}$ = Maximum possible impact score in Ecological Impact

- $W_{Geographic\ Extent}$ = weighted attribute of Geographic Extent (0.1)
- $W_{Invasive\ Potential}$ = weighted attribute of Invasive Potential (0.3)
- $W_{Ecological\ Impact}$ = weighted attribute of Ecological Impact (0.6)

Geographic Extent is of less importance in the scoring system and could also potentially be eliminated. It is thus given a low weighted impact of only 10 %. The reasons for this are: 1) Invasive species distribution is already considered in the category of Invasive Potential; 2) if every species is given a high score, in this case four out of four for all species, it would not make a big difference to the total impact scores relative to each other; 3) it could potentially be misleading when using equal weighting, in the way of only pushing the species higher up on the impact scale, and last; if integrated in a LCIA factor model, it could potentially already be accounted for if the characterization factor is region generic, and thus be regarded as double-counting.

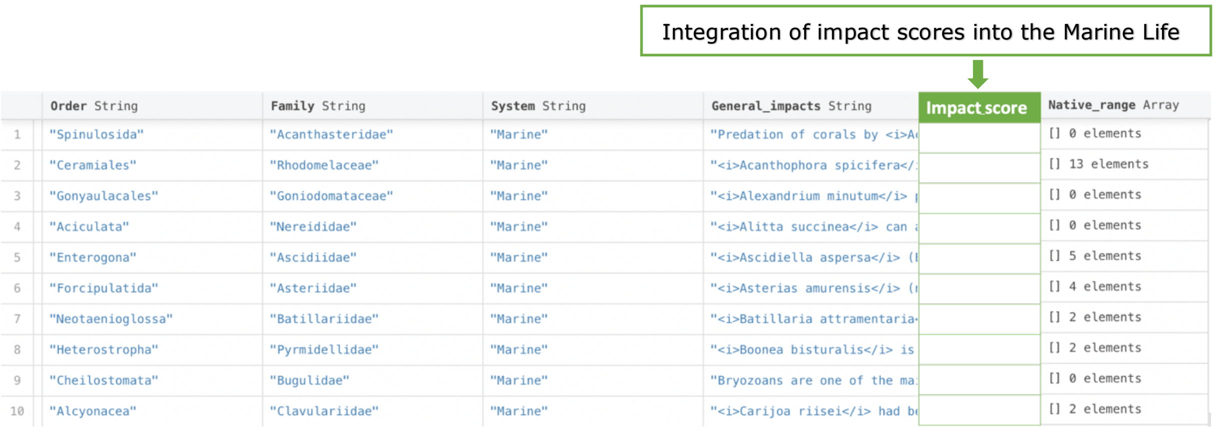
Another criterion worth to mention is Propagule Pressure, which is included in the category of Invasive Potential. Low access to data could potentially affect this criterion. However, Sandvik et al. (2013) define propagule pressure as a key parameter that influence both establishment and the first phase of spread and is thus positively correlated with expected population lifetime and the speed of the invasion front. These are all important factors to assess when considering environmental impacts, and an important reason why Propagule Pressure is included in the scoring system. The Marine Life database contains some descriptions on vectors for parasites and gene transmission, but collection of such data remains for future work (Myklebust, 2018).

Ecological Impact is considered to be of most importance and thus weighted greatest. The reason for this is that the scoring system was developed with the aim to integrate invasive species impact into a CF and EF factor model within the LCIA framework. This model is developed herein and specifically designed to indicate potential damage to the ecosystem quality area of protection. The scoring system considers thus environmental impacts only, and not human health, economics, or aesthetic aspects of landscape structure. However, Davidson et al. (2016) stress that "Given that risk assessments often occur in a sociopolitical context, including these additional core values will ensure the consequences to all stakeholders are fully accounted for". Hence, if a species is known to have economic impacts, but its environmental impacts have not been studied, one could assign it a low Ecological Impact score, pending more available data (Molnar et al., 2008). Management criteria and criteria for threatened landscape or species are excluded as well. Management criteria are excluded in consideration to the LCIA framework for the same reasons as socio-economic factors are excluded. The final impact category of a given alien species should rather inform than be influenced by alien species management (Sandvik et al., 2013). All species and ecosystems are considered to have an equivalent value, which is why impact on threatened landscape or species is excluded as a criterion in the scoring system. Excluding the latter will also prevent double counting of invasive species impact.

3.5 Integration of impact scores into the Marine Life Database

The platform used to visualize the integration of impact scores is MongoDB compass (MongoDB, 2018). The platform presents data in either list view or a table view of own choice. The data in Marine Life is organized as nested elements. In table view, one row represents one marine species. A row contains strings or arrays/objects of data/information on a marine species (for example a species' kingdom, phyla, order, family…), depending on the collection of choice (WoRMS, GISD or NatCon). The array data structure consists of nested elements, which means that an array allows for additional data on the species to be embed inside another, this data contains the same data type as the array name. The nested system of elements makes Marine Life a complex database. Because of this, IPython notebook and the Marine Life map is more efficient to use (if familiar with programming in Python), when retrieving or working with data in the Marine Life and Marine Life Map.

The impact scores are to be integrated in the Marine Life database. The impact scores can be added in a separate string beside the impact descriptions, as highlighted in green in Figure **3.3**. The impact scores are in the present example integrated in the GISD collection in Marine Life, that already contains impact descriptions (all screenshots of the collections are in appendix 2). See section 3.1 and 3.2 for details on GISD and Marine Life.



	Order String	Family String	System String	General_impacts String	Impact score	Native_range Array
1	"Spinulosida"	"Acanthasteridae"	"Marine"	"Predation of corals by <i>A		[] 0 elements
2	"Ceramiales"	"Rhodomelaceae"	"Marine"	"<i>Acanthophora spicifera</		[] 13 elements
3	"Gonyaulacales"	"Goniodomataceae"	"Marine"	"<i>Alexandrium minutum</i>		[] 0 elements
4	"Aciculata"	"Nereididae"	"Marine"	"<i>Alitta succinea</i> can		[] 0 elements
5	"Enterogona"	"Ascidiidae"	"Marine"	"<i>Ascidiella aspersa</i> (		[] 5 elements
6	"Forcipulatida"	"Asteriidae"	"Marine"	"<i>Asterias amurensis</i> (		[] 4 elements
7	"Neotaenioglossa"	"Batillariidae"	"Marine"	"<i>Batillaria attramentaria		[] 2 elements
8	"Heterostropha"	"Pyrmidellidae"	"Marine"	"<i>Boonea bisturalis</i> is		[] 2 elements
9	"Cheilostomata"	"Bugulidae"	"Marine"	"Bryozoans are one of the ma		[] 0 elements
10	"Alcyonacea"	"Clavulariidae"	"Marine"	"<i>Carijoa riisei</i> had b		[] 2 elements

Figure 3.3: Integration of impact score into the Marine Life Database

To make the integration of impact scores simple and transparent in the Marine Life database, the already integrated impact descriptions should be manipulated with. The impact descriptions in GISD are now in a string named "general_impact", containing unorganized information on each species' spread and impact. However, the scoring system considers three factors of importance; Geographic Extent, Invasive Potential and Ecological Impact. A suggestion is that the impact description of each species follows the impact categories of the scorings system. Hence, the invasive species impact descriptions could be structured by; "Geographic Extent", that considers only the non-native range of the alien invasive species; "Invasive Potential" that considers both rate of spread, expansion rate and propagule pressure, and; "Ecological Impact" considering Population dynamic effects, Effects on ecosystem structure (degradation of water quality and/or physical habitat), and Effects on ecosystem balance and functions (Nutrient viability, primary productivity, resource pools and supply rates).

Another way to integrate the impact scores to the Marine Life is having separate array objects for each impact category, where the impact descriptions are added accordingly together with the impact scores in two separate strings within the array/object. The total impact score of the assessed species can be included in a string of its own. An example of this suggestion is shown for invasive potential in Figure **3.4**.

Geographic_Extent Array	**Invasive_Potential** Array	**Ecological_Impact** Array	**Total_impact_score** string
[] 2 elements	[] 2 elements	[] 2 elements	" "
[] 2 elements	[] 2 elements	[] 2 elements	" "
[] 2 elements	[] 2 elements	[] 2 elements	" "
[] 2 elements	[] 2 elements	[] 2 elements	" "

Impact descriptions and impact scores within the array of invasive potential

Invasive_potential_description String	**Invasive_potential_score** String
" "	" "
" "	" "
" "	" "
" "	" "

Figure 3.4: Integration of impact scores in Marine Life

However, the integration of impact scores should rather be conducted after the impact description and other necessary data in all three collections in Marine Life are merged and organized. This allows for an easier implementation of the scoring system, where each score can be derived from a complete and well-founded data source. This remains for future work. Subsequently the scores can be integrated in the Marine Life Map.

4 Effect factor modelling towards an operational characterization factor

The object of the present thesis is to develop a quantification approach on marine invasive species impact on the endpoint level within the LCIA framework, more specifically into the area of protection "ecosystem quality" (Figure **4.1**).

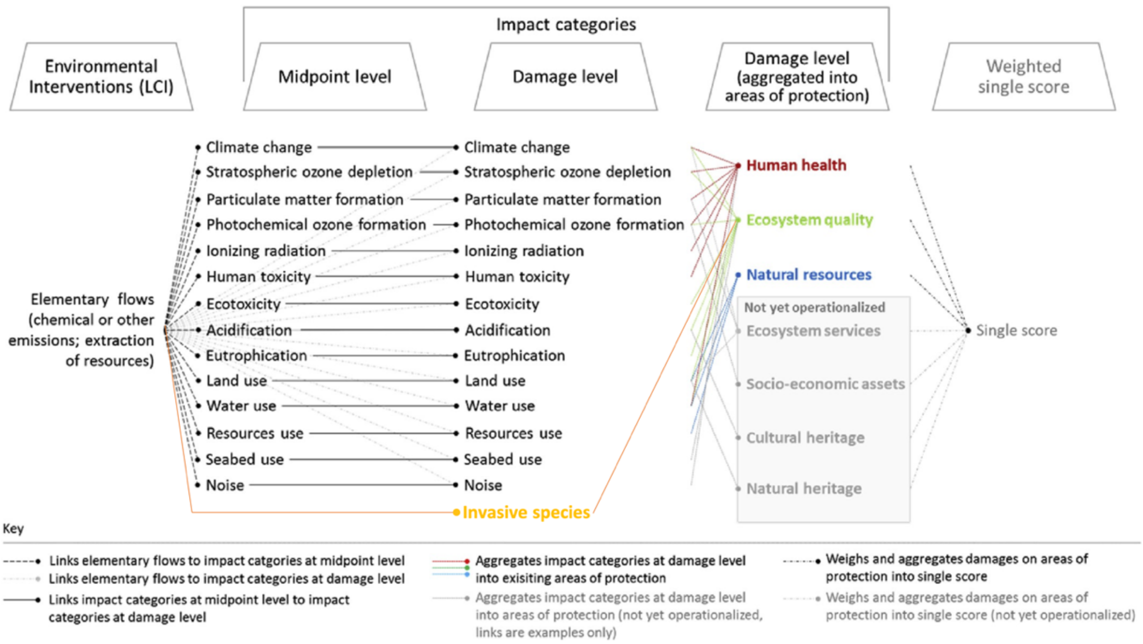


Figure 4.1: Mid- and endpoint indicators in LCIA modified from Verones et al. (2017). Endpoint levels in color show existing areas of protection. In orange, the new impact category for invasive species is indicated.

Such an endpoint model is based on a characterization factor that consists of the product of fate factor, the size of intervention, and effect factor, the effect/intensity of intervention (Curran et al., 2010). The aim is to integrate the impact scores in an approach for EF modelling for marine invasive species, which again could potentially be included in a complete LCIA model for marine invasive species impact. This LCIA model follow the impact pathway from the inventory of ballast water discharged due to marine transportation of goods to the indicator of ecosystem damage; PAF of native species, visualized in Figure **4.2**.

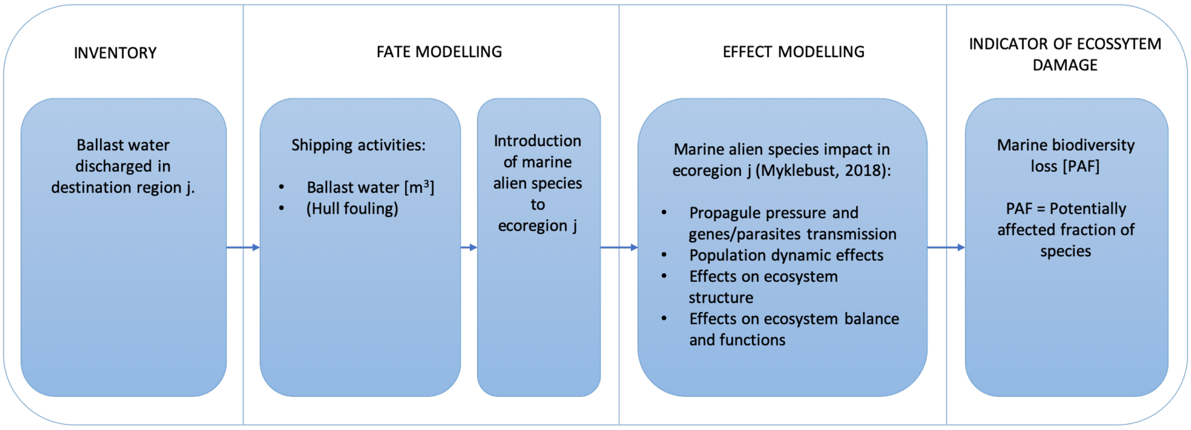


Figure 4.2: Marine invasive species impact pathway to ecosystem damage, arising from ballast water discharges in ecoregion j: linking inventory data to an indicator of ecosystem damage.

4.1 Modelling approach

In the present thesis a new quantitative approach for marine invasive species impacts is developed within the LCIA framework, where the underlying characterization factors follow the formula:

$$CF_j = FF_j \times XF_j \times EF_j$$

The CF_j is the characterization factor (PAF/m^3) for ballast water discharges in destination region j; FF_j is the fate factor for ecoregion j; XF_j is the exposure factor, and; EF_j is the effect factor, which is equivalent to the potentially affected fraction of species per unit stressor intensity in ecoregion j. The present model regards ecoregions only. An ecoregion is most likely not of most interest when linking inventory data to ecosystem damage, and to make the model more functional, either countries or shipping ports rather than ecoregions can be included. This however, remains for future work.

The characterization factor model follows the formula in Equation 3, and each factor is described in their own sections further below (4.1.1, 4.1.2 and 4.1.3).

$$CF_j = \underbrace{\frac{N_{alien,j}}{V_j}}_{FF_j} \times \underbrace{\frac{\sum_s IS_{s,j}}{N_{alien,j}}}_{XF_j} \times \underbrace{\frac{N_{affected,j}}{\frac{N_{native,j}}{\sum_s IS_{s,j}}}}_{EF_j}$$

Equation 3

CF_j describes the potential effect of marine invasive species introduced in spatially defined ocean regions in terms of a potentially affected fraction of species (PAF) per unit of ballast water (m^3). The CF is specific to the destination region of a shipping route, which means the characterization factor model focuses on the impact on a specific ecoregion j, and not the allocation of invasive species impact contribution from specific source regions. This means that the first port of call or last port of call of a shipping route is irrelevant as long as the destination port or destination region is known. Hence, the source regions are neglected for the present factor modelling, but also considered as irrelevant when aiming to derive a factor model only looking at the impact in ecoregion j. Neglecting source regions avoids double counting of marine invasive species, because if the same species was introduced from two different source regions to ecoregion j, they would be summed together and counted twice. In addition, neglecting source regions also avoids a model parameter concerning ballast water activity at drop off ports along the way to destination region j. There are ballast water exchanges whilst loading and unloading cargo in intermediate port, and the difficultly with this is that the amount of ballast water exchange at a port is highly variable. The latter basically makes the factor modelling difficult in the first place. It is thus very intricate to model the allocation of ballast water contribution from different ecoregions to destination region j. This is visualized in Figure **4.3** where a shipping route starts off from ecoregion i_1 with a drop off point in ecoregion i_2, and goes on further to its main destination, ecoregion j. The problem here is to estimate how much ballast water from i_1, and how much from i_2, is released in j. The figure also includes shipping transport from ecoregion i_2, i_3 and i_4, these combined with source region i_1, contribute to a total introduction of marine invasive species through ballast water to ecoregion j.

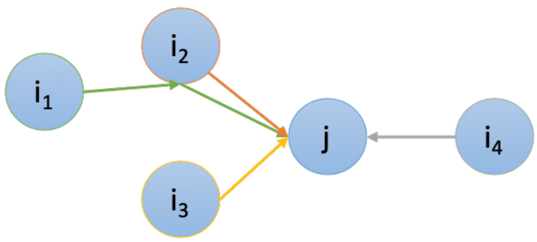


Figure 4.3: Visualization of four shipping routes to destination region j from source regions i_n.

4.1.1 Fate factor (FF_j)

The fate factor (Equation 4) is the environmental fate of invasive species introductions, and describes the fraction of alien species per m^3 ballast water introduced to ecoregion j. The parameters in FF_j are $N_{alien,j}$ and V_j, where $N_{alien,j}$ is the number of alien species in ecoregion j introduced from all potential source regions, here represented by the total number of alien species in ecoregion j (which is assumed to solely be a result of all ballast water discharges to date in ecoregion j).

$$FF_j = \frac{N_{alien,j}}{V_j}$$

Equation 4

$N_{alien,j}$ can be collected through the Marine Life Database (See section 3.3). The denominator V_j, is the total volume of ballast water (m^3) discharged in ecoregion j integrated over time from the reference year 1880 (when the use of ballast water began). To date, data on the latter is lacking, thus, the activity of marine shipping transport lays the basis for modelling the ballast water volume in ecoregion j. The possibilities of marine alien species introductions through ballast water started first in the 1880s (See section 2.1.1). Hence, 1880 is a reference year for zero ballast water in an ecoregion. An estimate of the number of ships (of different types) arriving to ports, within each ecoregion j in a recent year, is needed to estimate how much ballast water discharges these ships correspond to, and then extrapolate backwards to the reference year of zero. The total volume of ballast water discharges in j (V_j) can then be estimated using an integral over time. The case study (See chapter 5) provides an example of collecting such data, where a preliminary FF is derived to calculate a preliminary CF for SN.

4.1.2 Exposure factor (XF_j)

Both species and ecosystem are exposed to invasive species impact in the regions where alien species are introduced and established. The exposure factor (Equation 5), weights the severity of the alien species in ecoregion j, where; $\Sigma_s IS_{s,j}$ = Sum of impact scores of introduced species s in ecoregion j, and; $N_{alien,j}$ = The total number of alien species in ecoregion j.

$$XF_j = \frac{\sum_s IS_{s,j}}{N_{alien,j}}$$

Equation 5

The impact scores for each species can be calculated using the system presented in the present thesis (Section 3.4), and the total number of alien species can, as mentioned above, be collected through the Marine Life Database (See section 3.3). The sum of impact score represents the total impact the introduced species mediate in ecoregion j. Each impact score is between 0 and 1, where 0 means that the alien species mediate zero impact, while 1 is the highest impact a species can mediate. Hence, the impact score 1 represents a full invasive species equivalent. The sum of impact scores is divided by the total number of alien species in j, and an average invasive species impact contribution is thus derived.

4.1.3 Effect factor (EF_j):

The effect of alien species introductions is determined by the sensitivity the native species have to the mediated impact from the invasive species. The EF_j consists of; $N_{affected}$ = Total number of native species affected by invasive species in ecoregion j; N_{native} = total number of native species in j, and again; $\Sigma_s IS_{s,j}$ = Sum of impact scores for introduced species in ecoregion j. The complete EF formula is in Equation 6 on next page.

$$EF_j = \frac{PAF}{\sum_s IS_{s,j}} = \frac{N_{affected,j}}{\frac{N_{native,j}}{\sum_s IS_{s,j}}}$$

Equation 6

The EF represents the effect of invasive species impact in ecoregion j per pressure of invasive species equivalents (per impact score), hence per unit stressor intensity. The indicator of ecosystem damage is accounted for by a PAF-based metric which is measuring total effect of impact, and is derived by the number of species affected in j divided by the number of native species in j. The stressor intensity is defined by the sum of impact scores reflecting total intensity of pressure, allowing the EF to measure PAF per unit stressor intensity ($\Sigma_s IS_{s,j}$). This means that a higher PAF per intensity reflects a higher native species sensitivity to invasive species impact.

Data on both native and affected species can be collected through the Marine Life database (See section 3.3). And again, the impact scores for each species can be calculated using the system presented in the present thesis (See section 3.4).

5 Case study: Invasive species in Southern and Northern Norway

This chapter provides a case study of shipping in relation to ballast water discharges in Southern Norway and Northern Norway, that demonstrates the applicability of the new characterization/effect factor approach described in chapter 4. Effect factors and characterization factors are calculated for both of the ecoregions. However, to make it feasible to calculate a thr CF, assumptions were made on the ballast water parameter. The assumptions compensate for lack of data on ballast water discharges in the ecoregions of study, and they build upon descriptions of different shipping types and ballast water operations, which is further elaborated in the following sections in the present chapter. The characterization factors derived are thus not corresponding actual true values.

The ballast water volumes are derived in the following sections of this chapter, and remaining data was collected from the Marine Life database as explained in section 3.3. EF and CF were calculated for two marine ecoregions, Southern Norway and Northern Norway. Only the marine species groups and data available in the Marine Life are included in the calculations, brackish and freshwater species are excluded. The calculations are in appendix 6 and the results are presented in chapter (6). It is important to emphasize the results of this case study as not actual true values, because of the uncertain estimation of volume ballast water discharged into the ecoregions of study.

5.1 Methodology and material: Vessel Arrival statistics

The parameter $V_{j,}$ total volume of ballast water discharged in ecoregion j, cannot be collected through the Marine Life Database or found elsewhere. To estimate this parameter, data on maritime shipping traffic to Southern Norway and Northern Norway is needed. Data on vessels entering the ecoregions of study was thus collected through Statistic Norway (Statistics Norway, 2018), this includes number of arrivals by vessel type to the different ports of Southern Norway and Northern Norway (complete data in appendix 4 and associated query link in appendix 5). The port call statistics retrieved from Statistics Norway are based on data from SafeSeaNet, and the statistics include ships carrying cargo over 300 gross tons (Statistics Norway, 2018).

For the present case study, the included vessels are classified by tankers, bulk vessels and general cargos. Total maritime shipping arrivals to Southern Norway and Northern Norway in 2018 is presented in Table **5.1** and Table **5.2**.

Table 5.1: Vessel arrivals to Southern Norway 2018

Maritime transport statistics – Southern Norway (Statistics Norway, 2018)

Ship type	**Total arrivals by ship type in 2018**
Tanker	7423
Bulk vessel	5104
General cargo/other dry cargo vessel	27237
Total	39764

Table 5.2 Vessel arrivals to Northern Norway 2018

Maritime transport statistics – Northern Norway (Statistics Norway, 2018)

Ship type	**Total arrivals by ship type in 2018**
Tanker	725
Bulk vessel	1150
General cargo/other dry cargo vessel	3760
Total	5635

5.1.1 Maritime shipping details: Ballast water operation

Ballast water operations are necessary to Maintain ship stability, both during voyage and in ports (National Research Council et al., 1996). The ballast water operations are more specifically carried out (National Research Council et al., 1996):

- *"In ports to maintain clearance under cargo loading or cargo discharge facilities and the under-keel clearance so the vessel remains safely afloat"*
- *"To maintain the hull bending moments and shear forces within safe limits to avoid the catastrophic damage that can result from incorrect loading"*
- *"To Maintain the ship upright by trimming or heeling the ship"*

Typical vessel types and their ballast needs can be classified by the following operations (GloBallast, 2014) :

- *"Ballast replaces cargo: Ballast required in large quantities, primarily for return voyage".*
- *"Ballast for vessel control: Ballast required in almost all loading conditions to control stability, trim, and heel".*
- *"Ballast for loading and unloading cargo: Ballast taken on locally in large volumes and* discharged in same location"

Ballast water operations are relative complex. The operations depend on the size, configuration, and requirements of the ship and on the complexity of its pumping and piping systems (National Research Council et al., 1996). There is also no international standard unit of measurement for ballast, but for the present thesis cubic meters (m^3) is used as the unit of measurement. Because of different cargo distributions or fuel and water quantities on board, ships can have different ballast needs even though they are classified as the same vessel type and the locations and sizes of the ballast tanks are identical (National Research Council et al., 1996). These influencing factors described on ballast water operations make ballast water modelling difficult. Because of the latter and lack of ballast water data, the estimated volumes for the present case study do not represent true values, this is elaborated further in section 5.2 below.

5.2 Methodology and material: Ballast water volume estimates

David et al. (2012) identify three ballast water discharge models in his study on ballast water discharge; The European model, The Australian model and the North American Great Lakes studies. The European model is based on the assessment of the quantity of ballast water discharged in relation to the total quantity of cargo transshipped in a port by vessel type. The model used in Australian studies is based on average percentage of the relation between ballast capacity and deadweight tonnage (dwt). North American Great Lakes studies is based on the number of vessels and average ballast water carried, and this approach is implemented for the present case study and ballast water volume estimates.

Cope et al. (2015) examined the validity of the assumption that all ballast water originated from the last port of call and that all ballast water is subsequently discharged at the destination port. The results show that the discharge location was consistent with arrival port for 92.4% of discharged ballast water (by volume), and when discharge ecoregions were considered, the consistency increased to 98.2% of ballast water. And their research concluded with acceptable to use source and destination ports as a reasonable proxy for ballast uptake and discharge locations, respectively. These assumptions are also implemented for the present ballast water modelling and case study, hence, for all shipping arrivals to destination region SN and NN, ballast water is discharged.

Section 2.1.1 describes that depending on the size and purpose of the ship, 3-5 billion tons of ballast water is transferred globally each year. An individual ship carries anything from several hundred liters to more than 130 tons of ballast water, representing a volume of 130 m^3. Albert (2015) present data of ballast water capacities of three primary vessel types entering the Great Lakes from overseas between 2010 and 2013; Tanker, bulk vessels and general cargos. The data shows that bulkers have more than double the ballast water capacities of general cargo ships and small tankers for most years. The average capacities of tankers entering the Great Lakes were 5,687 to 10,132 MT. The average ballast water capacities for the bulkers ranged from 14,973 to 15,879 MT, while general cargo ships averaged between 4,599 to 6,003 MT of ballast water capacity. In several cases, a few very large vessels strongly influenced the means. For example, the four largest vessels in the great lakes were 740 feet long (Albert, 2015). The influence of different ship sizes', especially very large ships', ballast water volumes are a case of matter when comparing ecoregions to another. The vessels classified in both the study of Albert (2015) and in the present case study, are only categories of vessel types that can be subclassified by their size. Which means that a vessel of a specific ship type entering the Great Lakes could be of another size than the also same classified vessels entering Northern and Southern Norway. This applies to all ship types entering other ecoregions, and in addition, the ballast water operations vary accordingly. Hence, comparing ecoregions to one another is not of desire when collecting ballast water data.

However, because of lack of data on ship size, dwt, and ballast water operations for the ships entering Southern Norway and Northern Norway, the approach of the Great Lakes model is used herein. Numbers from Albert (2015)'s is thus generated into the present case study. Hence, it is assumed that the average ship size per vessel type entering Southern and Northern Norway are the same as the average ship size per vessel type entering the Great lakes. This however, lays a significant bias for the present case study as already mentioned; Ships entering The Great lakes or other ecoregions for the matter are not ideally comparable to one another as shipping traffic and statistics vary greatly (this includes, as elaborated in the section above, number of arrivals, source and destination regions, amount of cargo transported, ship types and their ship sizes and ballast water operations).

As the shipping traffic is continuously growing, numbers from the latest year of Albert (2015)'s study are chosen, hence 2013. By dividing the numbers on total ballast water discharged per ship type in 2013 by total respective ship type arrivals, average ballast water discharges per ship type entering the Great Lakes are derived (Table **5.3**).

Table 5.3: Ballast water discharged in The Great Lakes 2013

Ballast water discharged in The Great Lakes 2013 (Modified from Albert (2015))

Ship type	**Total arrivals**	**Ballast water discharged per ship (m^3)**	**Ballast water discharged (m^3)**
Tanker	87	309	26942
Bulk vessel	123	1684	207213
General cargo/other cargo vessel	73	1260	92008
Total	283	603 400	301 915

The volumes derived are generated to the present case study and multiplied with total arrivals by ship type to Southern region and Northern region of Norway (Table **5.4** and Table **5.5**). The total ballast water in 2018 for both regions are further extrapolated back to the reference year of zero and integrated over time to get the total amount of ballast water in the ecoregion of study. This is illustrated in Figure **5.1** for Southern Norway on next page, where V_{SN} = 8.28E+09 m^3. The same method is conducted to calculate ballast water discharged in Northern Norway, were total ballast water discharged is 7.6E+6 m^3.

Table 5.4: Ballast water discharged in Southern Norway in 2018

Ballast water discharged in Southern Norway in 2018

Ship type	**Total arrivals**	**Ballast water discharged per ship (m³)**	**Total ballast water discharged (m³)**
Tanker	7423	309	2 293 707
Bulk vessel	5104	1684	8 595 136
General cargo/other cargo vessel	27237	1260	34 318 620
Total	39764	603 400	239 935 976

Table 5.5 Ballast water discharged in Northern Norway in 2018

Ballast water discharged in Northern Norway in 2018

Ship type	**Total arrivals**	**Ballast water discharged per ship (m³)**	**Total ballast water discharged (m³)**
Tanker	725	309	355350
Bulk vessel	1150	1684	6331840
General cargo/other cargo vessel	3760	1260	913500
Total	5635	3253	7600690

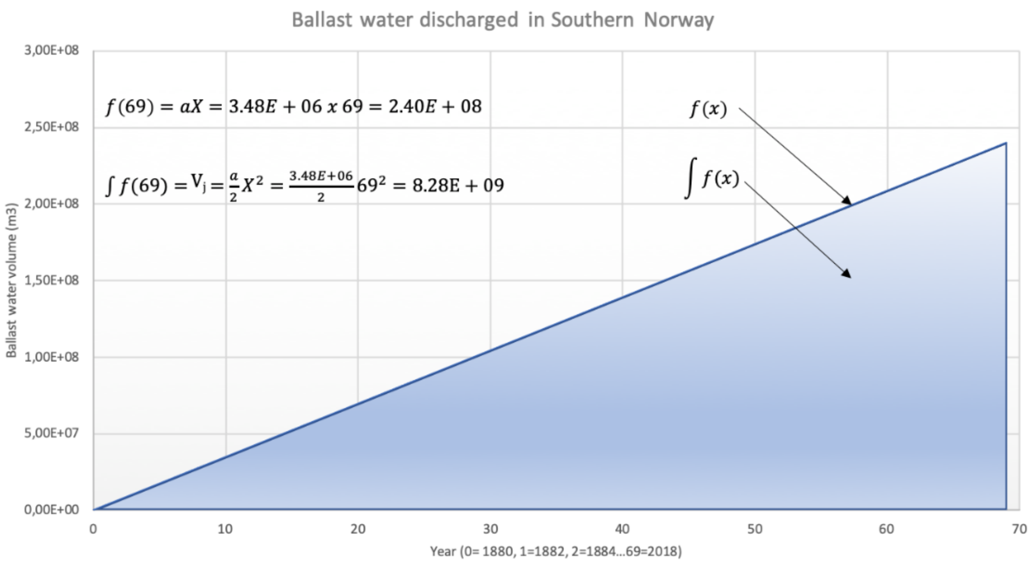


Figure 5.1: Total volume of ballast water discharged in Southern Norway

6 Results and discussion

The results of the case study are presented in this chapter. The preliminary characterization factors for Southern Norway and Northern Norway are presented and discussed, followed by the effect factors, as well as sections of relevant discussion (Spatial and temporal problems and model biases and uncertainties).

6.1 Characterization factors:

The preliminary CF for Southern Norway is 9,30E-13 PAF/m^3 (Equation 7), which means that a very small fraction of the native species in Southern Norway are potentially affected by every m^3 ballast water discharged in the region, due to invasive species impact. The same applies to the CF of Northern Norway, which is 6.23E-11 PAF/m^3 (Equation 8).

$$CF_{SN} = FF_{SN} \times XF_{SN} \times EF_{SN} = (7{,}25E-10)\frac{alien\ species}{m^3} \times 0{,}46 \times\ (2{,}77E-3)\ PAF = 9{,}30E-13\ \frac{PAF}{m^3}$$

Equation 7

$$CF_{NN} = FF_{NN} \times XF_{SN} \times EF_{NN} = (2.63E-7)\frac{alien\ species}{m^3} \times 0{,}5 \times\ (4.76E-4)\ PAF = 6.23E-11\ \frac{PAF}{m^3}$$

Equation 8

The CF of Northern Norway is 67 times bigger than the CF of Southern Norway region, which means that the PAF per m^3 ballast water is 67 times bigger in Northern Norway than Southern Norway. This is mostly influenced by the ballast water discharged in the regions, where V_{SN} = 2.40E+08 m^3 and V_{NN} = 7.60E+06 m^3. Southern Norway has more than 30 times bigger volume of ballast water in the region, which also results to a lower introduction of species per m^3 ballast water, which can be seen by the difference in FF of the regions ($\Delta FF = 2.64E-7$). The FF for Southern Norway is 7,25E-10 alien species per m^3 ballast water released. This would mean that for a very small fraction of the ballast water discharged in Southern Norway, alien species are present (have been introduced). The latter also applies to Northern Norway, where FF_{NN} = 2.63E-07 alien species/m^3.

The estimates of total ballast water volumes however, are influencing the results. Total ballast water for both ecoregions are probably an overestimate as the volume per year has most likely increased a lot more recently rather than linearly since 1880. The CF values are thus likely to be underestimated as a consequence. Hence, the ballast water volume is an uncertain parameter.

To date, the problem of invasive species introduction through shipping activity is highly recognized, and in 2004 The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted by IMO. The BWM Convention entered into force on 8 September 2017, and ships now need to manage their ballast waters (IMO, 2017). (IMO, 2019a) write that *"The Convention requires all ships to implement a ballast water management plan. All ships have to carry a ballast water record book and are required to carry out ballast water management procedures to a given standard".*

"There will be two different standards, corresponding to these two options", as follow (IMO, 2017):

> *"The D-1 standard requires ships to exchange their ballast water in open seas, away from coastal waters. Ideally, this means at least 200 nautical miles from land and in water at least 200 metres deep. By doing this, fewer organisms will survive and so ships will be less likely to introduce potentially harmful species when they release the ballast water.*
>
> *D-2 is a performance standard, which specifies the maximum amount of viable organisms allowed to be discharged, including specified indicator microbes harmful to human health.*
>
> *New ships must meet the D-2 standard from today while existing ships must initially meet the D-1 standard."*

And;

> *"Eventually, all ships will have to conform to the D-2 standard. For most ships, this involves installing special equipment*."

By following the D1 and D2 standards (2.1.1) the impacts per m^3 ballast water in SN an NN and other ecoregions can probably be lower in the future. This could potentially add an uncertainty to the relevance of using historical impacts to represent today's invasive species impacts in LCA. However, these management changes by the BWM convention will more likely affect the geographic extent, rate of introduction and alien species distribution, rather than the ecological impact of a species when first introduced. These changes could be accounted for by regularly updating marine species distributions, and the impact scores which are to be derived for each invasive species in the Marine Life. However, as impact scores are based on historical data, this is only doable after change has occurred. It would thus be necessary to continuously monitor both invasive species introductions and impact, as well as marine native and alien species distributions, to update the already collected data in The Marine Life. The BWM convention is a necessity and important step towards invasive species management, but invasive species impact is a comprehensive problem and a precautionary approach should be followed.

Nevertheless, Sandvik et al. (2013) stress that alien species may still be in the process of establishing or expanding when they are assessed. Hence, future invasion and impact potential should be based not only on estimates for the current situation, but also incorporate predictable changes in the foreseeable future (Sandvik et al., 2013). Screening-level risk assessment tools are imperfect (Drolet et al., 2016). It remains a paucity of consistency, consensus, and uniformity among approaches within biological invasion risk assessments (Davidson et al., 2016). However, because of the dynamic and potentially enormous threats posed by alien species, Sandvik et al. (2013) also stress that the precautionary principle should be followed when assessing the impact of marine alien species.

6.2 Effect factors:

The effect factors calculated in the case study show the potentially affected fraction of species per unit stressor intensity in both Northern Norway and Southern Norway (Table **6.1**).

Table 6.1 Effect factor for Southern Norway and Northern Norway

Effect factor for Southern Norway and Northern Norway

Marine ecoregions	**Effect Factors (PAF)**
Southern Norway	2,77E-3
Northern Norway	4,76E-4

The EF of Southern Norway is 2,77E-3 PAF, hence; 0,277 % of the native species are potentially affected per unit stressor intensity. In Northern Norway the PAF is less, with an EF of 4.76E-4 PAF per unit stressor intensity (0.0476 %). Despite that the average severity of the alien species invasiveness in both regions are quite the same, the EFs have a difference of about 83 %. Southern Norway is thus more affected per total impact mediated, hence per unit stressor intensity. This means that the native species in Southern Norway are most likely more sensitive to marine invasive species impact, than the native species in Northern Norway. As reported in section 3.1, there is only two alien species in Northern Norway, whereas Southern Norway that have six alien species in the region constituting to a higher total impact score. The intensity of impact is thus much bigger in Southern Norway.

6.3 The problem of spatial and temporal variation

The spatial (local, regional, national, continental, global; or islands only) and temporal (intermittent, seasonal, transient, and permanent) scale of a study are important factors when estimating an invasive species impact. A reason for this is that the population dynamics of both invaders and native species are expected to vary over space and time (Parker et al., 1999). Despite a net increase in species richness at small spatial scales, introduction of alien species can cause a decline in global species richness through extinction of native species (endemic or locally rare) (Jeschke et al., 2014).

Parker et al. (1999) emphasize that the inclusion or exclusion of predicted future impacts of an invasive species should be made explicit. They further stress that "some successful invaders increase steadily, and others exhibit more complex behavior, initially reaching very high densities but then declining to lower levels". Natural variation and temporal trends in the environment such as pollution, harvesting, or climate change, are additional factors that affect spatial and temporal variability of invasive species (Parker et al., 1999). An example of variation in the population dynamics of an invader is the brackish - and freshwater zebra mussel *Dreissena polymorpha* in Eastern Europe; with sixty years of monitoring, the study of Parker et al. (1999) revealed both expansion and contraction dynamics in some lakes, but steady logistic increase in others. Hence, there can be large differences between habitats and the short- and long-term impacts of alien species, making it hard to quantify the impacts of an invader.

Corridors are described as an introduction vector of marine alien species in 2.1.3, and the Suez Canal is a perfect example of spatial and temporal problems. It is documented a decline in overall richness of native species from the north-western to the south-eastern regions of the Mediterranean, and the opposite trend for alien species (Katsanevakis et al., 2013). This difference in spatial pattern of alien species biodiversity from native species biodiversity, contributes to changes in the overall biodiversity of the Mediterranean Sea. The consequences might be that native species rapidly get replaced by marine invasive species (Katsanevakis et al., 2013). For instance is the brine shrimp (*Artemia*) in the western Mediterranean, where the introduced brine shrimp (*A. Franciscana*) has shown to be an expanding invasive species regularly introduced since 1980, and now dominates the native brine shrimp (*A. Salina*) (Amat et al., 2005).

6.4 Model biases and uncertainties

Integration of impacts scores adds a sensitivity to the XF. In the XF the summed impact scores are divided by number of alien species in the region, meaning that an average impact is representing the exposure and weight of impact to ecoregion j. These scores are sensitive to the number of species assessed, in the way of potentially reducing the real impact mediated to ecoregion j to a low average impact contribution per species. For instance, if assessing an ecoregion where several species have low impact scores or some even mediating 0 impact, and only few species have very high impact score, this will result to a combined lower average species impact contribution. However, in reality, the recipient ecoregion is actually affected on a higher level, because of those few or that one species with a very high impact.

Further, the impact scores in the present thesis build upon the worst case scenario documented, which could have little to do with a true population impact (Parker et al., 1999). For example, Parker et al. (1999) stress that "if impacts are measured on species with marginal or ‘sink’ populations, extrapolating from a local impact could greatly exaggerate the real threat to global persistence", thus bringing up the problem of spatial and temporal variability (see section 6.3). True population impacts and the case of spatial and temporal problems can potentially influence the EF. Despite a net increase in species richness at small spatial scales, the introduction of alien species can cause a decline in global species richness through extinction of (endemic or locally rare) native species, resulting to an underestimation of the EF (see section 6.3). In the example of marine invasive species, global distributions of species vary; certain species may become extinct locally but not necessarily globally. However, local extinction of endemic species, for example, implicates also a global extinction (Koslowski, 2017). This could potentially be accounted for by upscaling the EF and thus examining how much local losses contribute to global ones (Chaudhary et al., 2015). This upscaling can be attained by, for instance, combining species-area models and vulnerability indicators (Chaudhary et al., 2015).

The present factor model does not include source regions, or an allocation factor regarding which ecoregion the alien species introductions and impacts in j belong to. The Shipping supply patterns vary, which makes allocating invasive species impact contribution per m^3 ballast water to source regions complex, especially if the route consists of intermediate ports. It is not sufficient to only allocate the contribution of impact based on the volume of ballast water in the FF. To avoid double counting it is also necessary to integrate which invasive species came from which source region's ballast. An alien species in ecoregion j can be native in different source ecoregions i, making it hard to avoid double counting. To integrate a parameter/allocation factor in the present modelling that takes this into account remains for future work. Neglecting source regions and an allocation factor in the present model has its influence on the life cycle inventory flow. The potential impact of the present inventory flow of 1 m^3 ballast water release is modelled from the basis of transportation of goods by ship to ecoregion j, which only accounts for where the goods are consumed. If including source regions in the model, the inventory flow would be ballast water discharged from ecoregion i to ecoregion j. In other words, this changes the interpretations of the results to also include the production distribution, meaning that the responsibility of invasive species impact in j is not only allocated to where the goods are consumed, but also where they are produced or distributed.

Ideally, ship owners prefer to complete all voyages with cargo. However, many trades and voyages require passage without cargo or in a light-cargo condition which influences the ships intake and discharge of ballast water. Data on ballast water discharges are highly important for the present factor model. For example, National Research Council et al. (1996) describe that a container ship may be fully loaded between two ports but may however proceed with only a partial load between the next two ports. This vessel sails therefore with some cargo and some ballast, whereas a crude oil tanker or iron ore carrier which typically transports a single cargo load between two ports, then returns to its point of origin or another port without cargo. In both, light cargo and empty conditions, the vessel requires ballast to operate safely and ballast water will thus be loaded during the return voyages (National Research Council et al., 1996). Since this vessel has already reached its destination port and is not transporting the goods originally of study anymore, the volume ballast water discharged during this ship's travel or arrival is not accounted for. Some of this volume ballast water intake is discharged when the ship is loaded with goods again for a new destination. However, this is in the source region and not the destination region and is thus not accounted for in the present model. The volume of ballast water varies not only by shipping type but also by the ballast water operations necessary in regard to the amount and weight of the cargo transported. Hence, if a ship arrived mostly empty (with lots of ballast water) and left with goods (and less ballast water) to destination region j, the ballast water discharges could potentially be much bigger in the source region rather than the destination region.

However, the present thesis follows the assumptions from Cope et al. (2015) (explained in section 5.2) that the discharge location is consistent with arrival ports, and thus arrival ecoregions. However, the variation in ballast water intake and discharge as discussed in the present thesis, emphasize the importance of facilitating for ballast water discharge records, so that such statistics can be collected and analyzed. Integrating ballast water variations in source ecoregions I and destination ecoregion j in the present factor model, remains for future work.

Another factor not taken into account is the tank size of the different vessels. A small tank size corresponds to a low likelihood of organism survival (due to lower oxygen levels, greater changes in temperature, and overall worse water quality) (GloBallast, 2014). Introductions of alien species per cubic meter ballast water could therefore vary by tank size. Data on the matter is not available at present date, and thus neglected in the present model. It is important to include such data in future. The factor model developed also neglects the other impact pathways described in the present thesis (2.1) and assumes all invasive species are introduced through ballast water only. Ballast water is responsible for a huge proportion of all invasive species introduction, but hull fouling is also recognized as an important vector of marine invasive species introductions (2.1.1). The inventory in the presented impact pathway is m^3 ballast water to ecoregion j. However, the impact is modelled from the basis of transportation of goods via shipping, and in addition to ballast water operations, hull fouling is also part of the shipping activities during the voyage to ecoregion j. This is not accounted for in the present factor modelling, and the invasive species impact in a region is not allocated to hull fouling, but ballast water only. Integrating hull fouling in the factor model, potentially through a separate inventory flow of m^2 fouled hull, remains for future work.

7 Conclusion and outlook

The impacts of alien species turning invasive are a growing concern. Assessing non-native invasive species in terms of their impact is thus essential for progress in ecology. The present thesis emphasizes ballast water as an important vector of marine invasive species introductions and presents an impact pathway that shows the link between inventory data, from; ballast water discharged in an ecoregion j, to; introduction of alien species through ballast water, to; the impact these species mediate in ecoregion j, and to; an indicator of ecosystem damage.

A preliminary CF and operational EF model was developed in the present thesis. The CF represents the potentially affected fraction of species (PAF) per m^3 ballast water discharged in ecoregion j. The CF includes a fate factor (FF), exposure factor (XF) and a complete operational effect factor (EF). The EF model constitutes the potentially affected fraction of species in region j derived on the total impact mediated from invasive species in the region. In other words, PAF per unit of stressor intensity. The level of influence from the invading alien species is estimated by using the scoring system developed in the pre-project for the current thesis, these scores are summed to represent the toal impact mediated.

The developed factor model was tested in a case study of invasive species introduced through ballast water in both Southern Norway and Northern Norway (and Finnmark). The preliminary CF for Southern Norway is 9,30E-13 PAF/m^3, and the CF of Northern Norway is 6.23E-11 PAF/m^3. While the EFs are 2,77E-3 PAF and 4,76E-4 PAF accordingly. The estimates of total ballast water volumes however, are influencing the CF results. Total ballast water for both ecoregions are probably an overestimate as the volume per year has most likely increased a lot more recently rather than linearly since 1880. The CF values are thus likely to be underestimated as a consequence. Hence, the ballast water volume is an uncertain parameter.

The CF model does not include source regions, or an allocation factor regarding which ecoregion's ballast water the alien species introductions and impacts in j belong to. Also, the model does not account for the problem of spatial and temporal variation, which can potentially underestimate the EF. This can be accounted for by upscaling the EF by, for instance, combining species-area models and vulnerability indicators. However, this remains for future work. In addition, in future work it is necessary to integrate the impact scores to the Marine Life database, and further develop the impact pathway and CF model. This includes; integration of ballast water discharge variations in source ecoregion i and destination ecoregion j, and; integration of hull fouling through a separate inventory flow of m^2 fouled hull.

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Appendix

Appendix 1: Query string – Historical development of peer-reviewed publications on marine invasive species

Appendix 2: Marine Life Database collections

Appendix 3: Impact scoring schemes

Appendix 4: Maritime transport statistics. Port calls by port, type of vessel, flag, contents and quarter (Southern and Northern Norway)

Appendix 5: Query links - Marine shipping data in Southern Norway and Northern Norway

Appendix 6: Impact scores, effect factors and case study calculations

Appendix 1: Query string – Historical development of peer-reviewed publications on marine invasive species

The query string used on Scopus search engine for historical development of peer-reviewed publications on marine invasive species (Figure **1**.**1**):

TITLE-ABS-KEY (((marine) OR (ocean*) OR (coast*)) AND (((invas*) OR (bio* AND invas*) OR (bioinvas*) OR (pollution) OR (biopollution) OR (introduct*)) AND (((non) AND ((nat*) OR (indig*))) OR (alien)) AND (species)) AND ((impact) OR (impact AND pathway) OR (impact AND assessment) OR (effect) OR (effect AND factor) OR (characterisation AND factor) OR (fate AND factor) OR (damage) OR (damage AND metric))) AND (LIMIT-TO (LANGUAGE , "English"))

Appendix 2: Marine Life Database collections

WoRMS Collection:

	_id ObjectId	AphiaID Int32	url String	scientificname String	authority Mixed
1	59a42619a18f392b9ada28e7	890400	"http://www.marinespecies.or	"Metacanthotrigonia monobean	"(Tashiro & Kozai, 1982
2	59a42619a18f392b9ada28e8	890401	"http://www.marinespecies.or	"Pterotrigonia (Scabrotrigon	"Tashiro & Kozai, 1982"
3	59a42619a18f392b9ada28e9	890402	"http://www.marinespecies.or	"Metacanthotrigonia pseudomo	"(Tashiro & Matsuda, 19
4	59a42619a18f392b9ada28ea	890403	"http://www.marinespecies.or	"Metacanthotrigonia pseudomo	null
5	59a42619a18f392b9ada28eb	890404	"http://www.marinespecies.or	"Pterotrigonia (Scabrotrigon	"Tashiro & Matsuda, 198
6	59a42619a18f392b9ada28ec	890405	"http://www.marinespecies.or	"Metacanthotrigonia moriana"	"(Yehara, 1923)"
7	59a42619a18f392b9ada28ed	890406	"http://www.marinespecies.or	"Metacanthotrigonia sakakura	"(Yehara, 1923)"
8	59a42619a18f392b9ada28ee	890407	"http://www.marinespecies.or	"Praescabrotrigonia emoryi"	"(Conrad, 1857)"
9	59a42619a18f392b9ada28ef	890408	"http://www.marinespecies.or	"Praescabrotrigonia bartrami"	"(Stephenson, 1923)"
10	59a42619a18f392b9ada28f0	890409	"http://www.marinespecies.or	"Praescabrotrigonia clavigera	"(Cragin, 1893)"

	status String	unacceptreason Mixed	rank String	valid_AphiaID Int32	valid_name String
1	"accepted"	null	"Species"	890400	"Metacanthotrigonia mono
2	"unaccepted"	null	"Species"	890400	"Metacanthotrigonia mono
3	"accepted"	null	"Species"	890402	"Metacanthotrigonia pseu
4	"unaccepted"	"misspelling"	"Species"	890402	"Metacanthotrigonia pseu
5	"unaccepted"	null	"Species"	890402	"Metacanthotrigonia pseu
6	"accepted"	null	"Species"	890405	"Metacanthotrigonia mori
7	"accepted"	null	"Species"	890406	"Metacanthotrigonia saka
8	"accepted"	null	"Species"	890407	"Praescabrotrigonia emor
9	"accepted"	null	"Species"	890408	"Praescabrotrigonia bart
10	"accepted"	null	"Species"	890409	"Praescabrotrigonia clav

	valid_authority String	kingdom String	phylum String	class String	order String
1	"(Tashiro & Kozai, 1982)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
2	"(Tashiro & Kozai, 1982)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
3	"(Tashiro & Matsuda, 1986)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
4	"(Tashiro & Matsuda, 1986)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
5	"(Tashiro & Matsuda, 1986)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
6	"(Yehara, 1923)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
7	"(Yehara, 1923)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
8	"(Conrad, 1857)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
9	"(Stephenson, 1923)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"
10	"(Cragin, 1893)"	"Animalia"	"Mollusca"	"Bivalvia"	"Trigoniida"

	family String	genus String	citation String	lsid String	isMarine Int32
1	"Pterotrigoniidae"	"Metacanthotrigonia"	"Schneider, S. (2016). Metac	"urn:lsid:marinespecies.org:	1
2	"Pterotrigoniidae"	"Pterotrigonia"	"Schneider, S. (2016). Ptero	"urn:lsid:marinespecies.org:	1
3	"Pterotrigoniidae"	"Metacanthotrigonia"	"Schneider, S. (2016). Metac	"urn:lsid:marinespecies.org:	1
4	"Pterotrigoniidae"	"Metacanthotrigonia"	"Schneider, S. (2017). Metac	"urn:lsid:marinespecies.org:	1
5	"Pterotrigoniidae"	"Pterotrigonia"	"Schneider, S. (2016). Ptero	"urn:lsid:marinespecies.org:	1
6	"Pterotrigoniidae"	"Metacanthotrigonia"	"Schneider, S. (2016). Metac	"urn:lsid:marinespecies.org:	1
7	"Pterotrigoniidae"	"Metacanthotrigonia"	"Schneider, S. (2016). Metac	"urn:lsid:marinespecies.org:	1
8	"Pterotrigoniidae"	"Praescabrotrigonia"	"Schneider, S. (2016). Praes	"urn:lsid:marinespecies.org:	1
9	"Pterotrigoniidae"	"Praescabrotrigonia"	"Schneider, S. (2016). Praes	"urn:lsid:marinespecies.org:	1
10	"Pterotrigoniidae"	"Praescabrotrigonia"	"Schneider, S. (2016). Praes	"urn:lsid:marinespecies.org:	1

	isBrackish Null	isFreshwater Null	isTerrestrial Null	isExtinct Mixed	match_type String
1	null	null	null	1	"exact"
2	null	null	null	1	"exact"
3	null	null	null	1	"exact"
4	null	null	null	1	"exact"
5	null	null	null	1	"exact"
6	null	null	null	1	"exact"
7	null	null	null	1	"exact"
8	null	null	null	1	"exact"
9	null	null	null	1	"exact"
10	null	null	null	1	"exact"

	restrial Null	isExtinct Mixed	match_type String	modified String	synonyms Array
1		1	"exact"	"2016-12-13T20:15:50Z"	[] 1 elements
2		1	"exact"	"2016-12-13T20:15:50Z"	No field
3		1	"exact"	"2016-12-13T20:15:50Z"	[] 2 elements
4		1	"exact"	"2017-02-26T19:04:33Z"	No field
5		1	"exact"	"2016-12-13T20:15:50Z"	No field
6		1	"exact"	"2016-12-13T20:15:50Z"	No field
7		1	"exact"	"2016-12-13T20:15:50Z"	[] 1 elements
8		1	"exact"	"2016-12-13T20:15:50Z"	[] 1 elements
9		1	"exact"	"2016-12-13T20:15:50Z"	[] 1 elements
10		1	"exact"	"2016-12-13T20:15:50Z"	[] 1 elements

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scientificname: "Metacanthotrigonia monobeana"
authority: "(Tashiro & Kozai, 1982)"
status: "accepted"
unacceptreason: null
rank: "Species"
valid_AphiaID: 890400
valid_name: "Metacanthotrigonia monobeana"
valid_authority: "(Tashiro & Kozai, 1982)"
kingdom: "Animalia"
phylum: "Mollusca"
class: "Bivalvia"
order: "Trigoniida"
family: "Pterotrigoniidae"
genus: "Metacanthotrigonia"
citation: "Schneider, S. (2016). Metacanthotrigonia monobeana. In: MolluscaBase ..."
lsid: "urn:lsid:marinespecies.org:taxname:890400"
isMarine: 1
isBrackish: null
isFreshwater: null
isTerrestrial: null
isExtinct: 1
match_type: "exact"
modified: "2016-12-13T20:15:50Z"
› synonyms: Array

HIDE 2 FIELDS

NatCon:

src_molnar

	_id ObjectId	Acanthogobius flavimanus Obj…	Acanthophora spicifera Object	Acar plicata Object	Acartia tonsa Object
1	59a91bcc4073d4325b600999	{} 36 fields	No field	No field	No field
2	59a91bcc4073d4325b60099a	No field	{} 36 fields	No field	No field
3	59a91bcc4073d4325b60099b	No field	No field	{} 36 fields	No field
4	59a91bcc4073d4325b60099c	No field	No field	No field	{} 36 fields
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7	59a91bcc4073d4325b60099f	No field	No field	No field	No field
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_id: ObjectId("59a91bcc4073d4325b600999")
Acanthogobius flavimanus: Object
Higher_taxa: "Vertebrate – fish"
Common_name: "Cá Bong (Viet Nam), Cá Bong hoa (Viet Nam), Japanese river goby, Mahaz..."
System_FrLandMar: "Marine, Freshwater"
Database_source: Array
Database_scope: "Invasive"
Ecos_services: null
Ag_pest: "No"
Ecol_Imp_Score: "3"
Ecol_Imp_Sources: Array
Ecol_Imp_Text: "Negatively interacts with native and endangered species competing for ..."
Scope_Score: "4"
Scope_Distribution: "Locally patchy"
Scope_Sources: Array
Scope_Text: null
Inv_Potl_Score: "3"
Inv_Potl_Sources: Array
Inv_Potl_Text: "Once established, this species spread in California, probably as a res..."
Mgt_Diff_Score: "4"
Mgt_Diff_Sources: Array
Mgt_Diff_Text: "Have not been able to eradicate or control this species from Californi..."
Origin: "Asia"
Intro_text: "Introduced to Australia and the West Coast of North America. 1963 intr..."
1st_Intro_date: "1963"
Non_nat_country-pri: "USA"
Non_nat_text-pri: null
Non_nat_country-sec: "Australia"
Non_nat_text-sec: "Port Philip Bay, Victoria & Sydney Harbour & Adelaide, Australia,"
Habitat1: "marine habitats"
Habitat2: "brackish water"
Habitat3: "water courses"
Habitat4: "coastland"
Habitat5: "estuaries/bays"
Habitat_text: "usually found in freshwater reaches of streams just above tidal influe..."
Geo_Hab_ref: Array
pathways: Array
distribution: Array

GISD Collection:

	_id ObjectId	Species String	Kingdom String	Phylum String	Class String
1	59a91bcd4073d4325b600c4d	"Acanthaster planci"	"Animalia"	"Echinodermata"	"Asteroidea"
2	59a91bcd4073d4325b600c4e	"Acanthophora spicifera"	"Plantae"	"Rhodophyta"	"Florideophiceae"
3	59a91bcd4073d4325b600c4f	"Alexandrium minutum"	"Plantae"	"Pyrrophycophyta"	"Dinophyceae"
4	59a91bcd4073d4325b600c50	"Alitta succinea"	"Animalia"	"Annelida"	"Polychaeta"
5	59a91bcd4073d4325b600c51	"Ascidiella aspersa"	"Animalia"	"Chordata"	"Ascidiacea"
6	59a91bcd4073d4325b600c52	"Asterias amurensis"	"Animalia"	"Echinodermata"	"Asteroidea"
7	59a91bcd4073d4325b600c53	"Batillaria attramentaria"	"Animalia"	"Mollusca"	"Gastropoda"
8	59a91bcd4073d4325b600c54	"Boonea bisuturalis"	"Animalia"	"Mollusca"	"Gastropoda"
9	59a91bcd4073d4325b600c55	"Bugula neritina"	"Animalia"	"Ectoprocta"	"Gymnolaemata"
10	59a91bcd4073d4325b600c56	"Carijoa riisei"	"Animalia"	"Cnidaria"	"Anthozoa"

	Order String	Family String	System String	General_impacts String	Native_range Array
1	"Spinulosida"	"Acanthasteridae"	"Marine"	"Predation of corals by <i>A	[] 0 elements
2	"Ceramiales"	"Rhodomelaceae"	"Marine"	"<i>Acanthophora spicifera</	[] 13 elements
3	"Gonyaulacales"	"Goniodomataceae"	"Marine"	"<i>Alexandrium minutum</i>	[] 0 elements
4	"Aciculata"	"Nereididae"	"Marine"	"<i>Alitta succinea</i> can	[] 0 elements
5	"Enterogona"	"Ascidiidae"	"Marine"	"<i>Ascidiella aspersa</i> (	[] 5 elements
6	"Forcipulatida"	"Asteriidae"	"Marine"	"<i>Asterias amurensis</i> (	[] 4 elements
7	"Neotaenioglossa"	"Batillariidae"	"Marine"	"<i>Batillaria attramentaria	[] 2 elements
8	"Heterostropha"	"Pyrmidellidae"	"Marine"	"<i>Boonea bisturalis</i> is	[] 2 elements
9	"Cheilostomata"	"Bugulidae"	"Marine"	"Bryozoans are one of the ma	[] 0 elements
10	"Alcyonacea"	"Clavulariidae"	"Marine"	"<i>Carijoa riisei</i> had b	[] 2 elements

```
_id: ObjectId("59a91bcd4073d4325b600c4d")
Species: "Acanthaster planci"
Kingdom: "Animalia"
Phylum: "Echinodermata"
Class: "Asteroidea"
Order: "Spinulosida"
Family: "Acanthasteridae"
System: "Marine"
General_impacts: "Predation of corals by <i>Acanthaster planci</i>, storm damage, coral ..."
> Native_range: Array
> Alien_range: Object
```

```
_id: ObjectId("59a91bcd4073d4325b600c4e")
Species: "Acanthophora spicifera"
Kingdom: "Plantae"
Phylum: "Rhodophyta"
Class: "Florideophiceae"
Order: "Ceramiales"
Family: "Rhodomelaceae"
System: "Marine"
General_impacts: "<i>Acanthophora spicifera</i> has a plastic morphology, which allows i..."
> Native_range: Array
> Alien_range: Object
```

```
_id: ObjectId("59a91bcd4073d4325b600c4f")
Species: "Alexandrium minutum"
Kingdom: "Plantae"
Phylum: "Pyrrophycophyta"
Class: "Dinophyceae"
Order: "Gonyaulacales"
Family: "Goniodomataceae"
System: "Marine"
General_impacts: "<i>Alexandrium minutum</i> produces toxins which are toxic to some zoo..."
> Native_range: Array
> Alien_range: Object
```

Appendix 3: Impact scoring schemes and calculations

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

MYA ARENARIA

A) GEOGRAPHIC EXTENT – 10 %

– **Geographic extent**

✓ (4) – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
3 – Ecoregion - Established in no more than two adjoining ecoregions.
2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
1 – Single site – single locality.
0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

– **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**

4 – Species has rapidly been introduced to areas of suitable habitat.
3 – Species has less rapidly been introduced to areas of suitable habitat.
✓ (2) – Species has regularly been introduced to areas of suitable habitat.
1 – Species has seldom been introduced to areas of suitable habitat.
0 – Unknown or not enough information to determine score.

– **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**

4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
✓ (3) – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
2 – Established/present, but not currently spreading.
1 – Species has not spread/invaded once introduced.
0 – Unknown or not enough information to determine score.

– **Propagule pressure criteria (The risks of transmitting genes or parasites).**

4 – Documented events of both genes and parasites transmission.
3 – Do cause either genes or parasites transmission to native species.
2 – Possibility of transmitting parasites and genes to native species.
1 – Minor possibility of transmitting genes and parasites
✓ (0) – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

– **Population dynamic effects – in what grade do the alien species interact with native species.**

✓ (4) – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
0 – Unknown or not enough information to determine score.

– **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**

✓ (4) – Causing large scale changes by altering community structure
3 – Cause medium to large documented impacts on community structure
2 – Cause small to medium documented impacts on community structure
1 – Causing minor impact on community structure
0 – Unknown

– **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**

4 – Causing large scale changes by altering ecosystem balance and functions
✓ (3) – Cause medium to large documented impacts on ecosystem balance and functions
2 – Cause small to medium documented impacts on ecosystem balance and functions
1 – Causing minor impact on ecosystem balance and functions
0 – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

COSCINODISCUS WAILESII

A) GEOGRAPHIC EXTENT – 10 %

- **Geographic extent**
  - ✓(4)– Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  - 3 – Ecoregion - Established in no more than two adjoining ecoregions.
  - 2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  - 1 – Single site – single locality.
  - 0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

- **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**
  - 4 – Species has rapidly been introduced to areas of suitable habitat.
  - 3 – Species has less rapidly been introduced to areas of suitable habitat.
  - 2 – Species has regularly been introduced to areas of suitable habitat.
  - 1 – Species has seldom been introduced to areas of suitable habitat.
  - ✓(0)– Unknown or not enough information to determine score.
- **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**
  - 4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  - 3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  - ✓(2)– Established/present (but not currently spreading. → UNKNOWN)
  - 1 – Species has not spread/invaded once introduced.
  - 0 – Unknown or not enough information to determine score.
- **Propagule pressure criteria (The risks of transmitting genes or parasites).**
  - 4 – Documented events of both genes and parasites transmission.
  - 3 – Do cause either genes or parasites transmission to native species.
  - 2 – Possibility of transmitting parasites and genes to native species.
  - 1 – Minor possibility of transmitting genes and parasites
  - ✓(0)– Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

- **Population dynamic effects – in what grade do the alien species interact with native species.**
  - 4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  - 3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  - 2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  - 1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  - ✓(0)– Unknown or not enough information to determine score.
- **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**
  - 4 – Causing large scale changes by altering community structure
  - ✓(3)– Cause medium to large documented impacts on community structure
  - 2 – Cause small to medium documented impacts on community structure
  - 1 – Causing minor impact on community structure
  - 0 – Unknown
- **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**
  - 4 – Causing large scale changes by altering ecosystem balance and functions
  - 3 – Cause medium to large documented impacts on ecosystem balance and functions
  - 2 – Cause small to medium documented impacts on ecosystem balance and functions
  - ✓(1)– Causing minor impact on ecosystem balance and functions
  - 0 – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

CIONA INTESTINALIS

A) GEOGRAPHIC EXTENT – 10 %

- **Geographic extent**

  ✓ (4) – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  3 – Ecoregion - Established in no more than two adjoining ecoregions.
  2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  1 – Single site – single locality.
  0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

- **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**

  ✓ (4) – Species has rapidly been introduced to areas of suitable habitat.
  3 – Species has less rapidly been introduced to areas of suitable habitat.
  2 – Species has regularly been introduced to areas of suitable habitat.
  1 – Species has seldom been introduced to areas of suitable habitat.
  0 – Unknown or not enough information to determine score.

- **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**

  ✓ (4) – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  2 – Established/present, but not currently spreading.
  1 – Species has not spread/invaded once introduced.
  0 – Unknown or not enough information to determine score.

- **Propagule pressure criteria (The risks of transmitting genes or parasites).**

  4 – Documented events of both genes and parasites transmission.
  3 – Do cause either genes or parasites transmission to native species.
  2 – Possibility of transmitting parasites and genes to native species.
  1 – Minor possibility of transmitting genes and parasites
  ✓ (0) – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

- **Population dynamic effects – in what grade do the alien species interact with native species.**

  ✓ (4) – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  0 – Unknown or not enough information to determine score.

- **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**

  4 – Causing large scale changes by altering community structure
  ✓ (3) – Cause medium to large documented impacts on community structure
  2 – Cause small to medium documented impacts on community structure
  1 – Causing minor impact on community structure
  0 – Unknown

- **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**

  ✓ (4) – Causing large scale changes by altering ecosystem balance and functions
  3 – Cause medium to large documented impacts on ecosystem balance and functions
  2 – Cause small to medium documented impacts on ecosystem balance and functions
  1 – Causing minor impact on ecosystem balance and functions
  0 – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

CORETHRON CRIOPHILUM

A) GEOGRAPHIC EXTENT – 10 %

- **Geographic extent**
  - ✓ (4) – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  - 3 – Ecoregion - Established in no more than two adjoining ecoregions.
  - 2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  - 1 – Single site – single locality.
  - 0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

- **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**
  - 4 – Species has rapidly been introduced to areas of suitable habitat.
  - 3 – Species has less rapidly been introduced to areas of suitable habitat.
  - 2 – Species has regularly been introduced to areas of suitable habitat.
  - 1 – Species has seldom been introduced to areas of suitable habitat.
  - ✓ (0) – Unknown or not enough information to determine score.
- **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**
  - 4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  - 3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  - 2 – Established/present, but not currently spreading.
  - 1 – Species has not spread/invaded once introduced.
  - ✓ (0) – Unknown or not enough information to determine score.
- **Propagule pressure criteria (The risks of transmitting genes or parasites).**
  - 4 – Documented events of both genes and parasites transmission.
  - 3 – Do cause either genes or parasites transmission to native species.
  - 2 – Possibility of transmitting parasites and genes to native species.
  - 1 – Minor possibility of transmitting genes and parasites
  - ✓ (0) – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

- **Population dynamic effects – in what grade do the alien species interact with native species.**
  - 4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  - 3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  - 2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  - ✓ (1) – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  - 0 – Unknown or not enough information to determine score.
- **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**
  - ✓ (4) – Causing large scale changes by altering community structure
  - 3 – Cause medium to large documented impacts on community structure
  - 2 – Cause small to medium documented impacts on community structure
  - 1 – Causing minor impact on community structure
  - 0 – Unknown
- **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**
  - 4 – Causing large scale changes by altering ecosystem balance and functions
  - ✓ (3) – Cause medium to large documented impacts on ecosystem balance and functions
  - 2 – Cause small to medium documented impacts on ecosystem balance and functions
  - 1 – Causing minor impact on ecosystem balance and functions
  - 0 – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

RHIZOSOLENIA INDICA

A) GEOGRAPHIC EXTENT – 10 %

– **Geographic extent**
  - ✓(4) – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  - 3 – Ecoregion - Established in no more than two adjoining ecoregions.
  - 2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  - 1 – Single site – single locality.
  - 0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

– **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**
  - 4 – Species has rapidly been introduced to areas of suitable habitat.
  - 3 – Species has less rapidly been introduced to areas of suitable habitat.
  - 2 – Species has regularly been introduced to areas of suitable habitat.
  - 1 – Species has seldom been introduced to areas of suitable habitat.
  - ✓(0) – Unknown or not enough information to determine score.

– **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**
  - 4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  - 3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  - 2 – Established/present, but not currently spreading.
  - 1 – Species has not spread/invaded once introduced.
  - ✓(0) – Unknown or not enough information to determine score.

– **Propagule pressure criteria (The risks of transmitting genes or parasites).**
  - 4 – Documented events of both genes and parasites transmission.
  - 3 – Do cause either genes or parasites transmission to native species.
  - 2 – Possibility of transmitting parasites and genes to native species.
  - 1 – Minor possibility of transmitting genes and parasites
  - ✓(0) – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

– **Population dynamic effects – in what grade do the alien species interact with native species.**
  - 4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  - 3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  - 2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  - 1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  - ✓(0) – Unknown or not enough information to determine score.

– **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**
  - 4 – Causing large scale changes by altering community structure
  - 3 – Cause medium to large documented impacts on community structure
  - 2 – Cause small to medium documented impacts on community structure
  - 1 – Causing minor impact on community structure
  - ✓(0) – Unknown

– **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**
  - 4 – Causing large scale changes by altering ecosystem balance and functions
  - 3 – Cause medium to large documented impacts on ecosystem balance and functions
  - 2 – Cause small to medium documented impacts on ecosystem balance and functions
  - 1 – Causing minor impact on ecosystem balance and functions
  - ✓(0) – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT

SALMACINA DYSTERI

A) GEOGRAPHIC EXTENT – 10 %

– **Geographic extent**

✓ (4) – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
3 – Ecoregion - Established in no more than two adjoining ecoregions.
2 – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
1 – Single site – single locality.
0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

– **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**

4 – Species has rapidly been introduced to areas of suitable habitat.
3 – Species has less rapidly been introduced to areas of suitable habitat.
2 – Species has regularly been introduced to areas of suitable habitat.
1 – Species has seldom been introduced to areas of suitable habitat.
✓ (0) – Unknown or not enough information to determine score.

– **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**

4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
3 – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
✓ (2) – Established/present, but not currently spreading.
1 – Species has not spread/invaded once introduced.
0 – Unknown or not enough information to determine score.

– **Propagule pressure criteria (The risks of transmitting genes or parasites).**

4 – Documented events of both genes and parasites transmission.
3 – Do cause either genes or parasites transmission to native species.
2 – Possibility of transmitting parasites and genes to native species.
1 – Minor possibility of transmitting genes and parasites
✓ (0) – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

– **Population dynamic effects – in what grade do the alien species interact with native species.**

4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
3 – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
✓ (1) – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
0 – Unknown or not enough information to determine score.

– **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**

4 – Causing large scale changes by altering community structure
3 – Cause medium to large documented impacts on community structure
2 – Cause small to medium documented impacts on community structure
1 – Causing minor impact on community structure
✓ (0) – Unknown

– **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**

4 – Causing large scale changes by altering ecosystem balance and functions
3 – Cause medium to large documented impacts on ecosystem balance and functions
2 – Cause small to medium documented impacts on ecosystem balance and functions
1 – Causing minor impact on ecosystem balance and functions
✓ (0) – Unknown or not enough information to determine score.

SCORING SYSTEM OF MARINE INVASIVE SPECIES IMPACT N. Norway / F

PARALITHODES CAMTSCHATICUS

A) GEOGRAPHIC EXTENT – 10 %

- **Geographic extent**
  - 4 – Multi-ecoregion - Spans three or more ecoregions, cross continental, trans-oceanic.
  - 3 – Ecoregion - Established in no more than two adjoining ecoregions.
  - (2) – Local ecosystem/sub-ecoregion - More than one occurrence within one ecosystem.
  - 1 – Single site – single locality.
  - 0 – Unknown or not enough information to determine score.

B) INVASIVE POTENTIAL - 30 %

- **Rate of spread: In what grade is the alien species introduced to areas of suitable habitat (habitats where the alien species can, once have, or are likely to establish).**
  - 4 – Species has rapidly been introduced to areas of suitable habitat.
  - 3 – Species has less rapidly been introduced to areas of suitable habitat.
  - 2 – Species has regularly been introduced to areas of suitable habitat.
  - (1) – Species has seldom been introduced to areas of suitable habitat.
  - 0 – Unknown or not enough information to determine score.
- **Expansion rate: Expansion rate and potential for future spread once introduced in a new habitat**
  - 4 – Currently/recently spreading rapidly, and likely to spread quickly after new invasions and/or species has spread/invaded rapidly, doubling in < 10 years, after past introductions.
  - (3) – Currently/recently spreading at a high rate, and potential for future, rapid spreading after new invasion (Species has spread/invaded after past introductions).
  - 2 – Established/present, but not currently spreading.
  - 1 – Species has not spread/invaded once introduced.
  - 0 – Unknown or not enough information to determine score.
- **Propagule pressure criteria (The risks of transmitting genes or parasites).**
  - 4 – Documented events of both genes and parasites transmission.
  - 3 – Do cause either genes or parasites transmission to native species.
  - (2) – Possibility of transmitting parasites and genes to native species.
  - 1 – Minor possibility of transmitting genes and parasites
  - 0 – Unknown or not enough information to determine score.

C) ECOLOGICAL IMPACT – 60 %

- **Population dynamic effects – in what grade do the alien species interact with native species.**
  - 4 – Causing large scale Impact to a number of species (competitive interspecific relationships and reduction of food supply), significant reduction in native species abundance (reduced growth or reproduction) and/or native species richness (reduced biodiversity or loss of biodiversity). Do displace native species and/or cause localized to widespread extinctions.
  - (3) – Causing medium to large scale Impact to a number of specie (competitive interspecific relationships and reduction of food supply), decreasing native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), potentially displacing native species without causing localized extinctions.
  - 2 – Causing impact to a small-medium scale to a number of species (competitive interspecific relationships and reduction of food supply), interfere native species abundance (reduced growth or reproduction, in the face of predators or competitor) and/or native species richness (reduced biodiversity or loss of biodiversity), but do not displace native species or cause extinctions.
  - 1 – Causing minor impact to a species or species group, with no wider known impacts and without causing extinctions.
  - 0 – Unknown or not enough information to determine score.
- **Effects on ecosystem structure (degradation of water quality and/or physical habitat)**
  - 4 – Causing large scale changes by altering community structure
  - 3 – Cause medium to large documented impacts on community structure
  - (2) – Cause small to medium documented impacts on community structure
  - 1 – Causing minor impact on community structure
  - 0 – Unknown
- **Effects on ecosystem balance and functions (Nutrient availability, primary productivity, resource pools and supply rates)**
  - (4) – Causing large scale changes by altering ecosystem balance and functions
  - 3 – Cause medium to large documented impacts on ecosystem balance and functions
  - 2 – Cause small to medium documented impacts on ecosystem balance and functions
  - 1 – Causing minor impact on ecosystem balance and functions
  - 0 – Unknown or not enough information to determine score.

Ciona intestinalis

$4 + | 4 + 4 + 0 + | 4 + 3 + 4 = 23/28$

$\frac{4}{4} \cdot 0{,}1 + \frac{8}{12} \cdot 0{,}3 + \frac{11}{12} \cdot 0{,}6 = \underline{0{,}85}$

Found in: merge

Corethron Criophilum

$4 + | 0 + 0 + 0 + | 1 + 4 + 3 = 12/28$

$\frac{4}{4} \cdot 0{,}1 + \frac{0}{12} \cdot 0{,}3 + \frac{8}{12} \cdot 0{,}6 = \underline{0{,}500}$

Found in src_worms_all : unaccepted,
→ unassessed
→ lack of data

Coscinoiscus wailesii

$4 + | 0 + 2 + 0 + | 0 + 3 + 1 = 10/28$

$\frac{4}{4} \cdot 0{,}1 + \frac{2}{12} \cdot 0{,}3 + \frac{4}{12} \cdot 0{,}6 = \underline{0{,}350}$

Found in src_worms_invasive

Mya arneria

$4 + | 2 + 3 + 0 + | 4 + 4 + 3 = 20/28$

$\frac{4}{4} \cdot 0{,}1 + \frac{5}{12} \cdot 0{,}3 + \frac{11}{12} \cdot 0{,}6 = \underline{0{,}775}$

found in: Merge

Rhizosolenia Indica (data lacking)

$4 + | 0 + 0 + 0 + | 0 + 0 + 0 = 4/82$

$0{,}1 + 0 + 0 = \underline{0{,}1}$

found in: src_worms_all - unaccepted
→ synonym

Salmacina dysteri (data lacking)

$4 + | 0 + 2 + 0 + | 1 + 0 + 0 = 7/28$

$\frac{4}{4} \cdot 0{,}1 + \frac{2}{12} \cdot 0{,}3 + \frac{1}{12} \cdot 0{,}6 = \underline{0{,}2}$

found in: Merge

Paralithodes camtschaticus

2 + | 1 + 3 + 2 + | 3 + 2 + 4

$$\frac{2}{4} \cdot 0{,}1 + \frac{6}{12} \cdot 0{,}3 + \frac{9}{12} \cdot 0{,}6 = \underline{0{,}65}$$

found in: merge

Appendix 4: Maritime transport statistics. Port calls by port, type of vessel, flag, contents and quarter, modified from Statistics Norway (2018).

09518: MARITIME TRANSPORT STATISTICS. PORT CALLS BY PORT, TYPE OF VESSEL, FLAG, CONTENTS AND QUARTER (SOUTHERN NORAY)

PORTS IN SOUTHERN NORWAY	Ship type	Arrivals of vessels				
		2018 K1	**2018 K2**	**2018 K3**	**2018 K4**	2018
FREDRIKSTAD (BORG)	**Tanker**	85	75	83	84	327
	Bulk vessel	12	7	9	7	35
	General cargo/other dry cargo vessel	230	235	235	257	957
MOSS	**Tanker**	13	12	11	8	44
	Bulk vessel	0	3	2	5	10
	General cargo/other dry cargo vessel	94	92	88	104	378
OSLO	**Tanker**	61	54	65	68	248
	Bulk vessel	29	16	15	13	73
	General cargo/other dry cargo vessel	360	424	390	424	1598
DRAMMEN	**Tanker**	7	19	26	29	81
	Bulk vessel	22	26	28	15	91
	General cargo/other dry cargo vessel	318	346	286	338	1288
TØNSBERG	**Tanker**	167	159	169	161	656
	Bulk vessel	1	0	0	0	1
	General cargo/other dry cargo vessel	37	39	36	29	141
SANDEFJORD	**Tanker**	7	6	4	4	21
	Bulk vessel	1	0	0	0	1
	General cargo/other dry cargo vessel	52	17	1	2	72
LARVIK	**Tanker**	6	7	6	6	25
	Bulk vessel	3	5	2	2	12
	General cargo/other dry cargo vessel	126	129	100	94	449
PORSGRUNN (GRENLAND)	**Tanker**	188	175	190	190	743
	Bulk vessel	130	119	136	124	509
	General cargo/other dry cargo vessel	360	361	370	391	1482
KRISTIANSAND	**Tanker**	25	23	27	30	105
	Bulk vessel	21	20	18	22	81
	General cargo/other dry cargo vessel	120	143	124	132	519
FARSUND	**Tanker**	0	0	0	0	0

	Bulk vessel	0	0	0	0	0
	General cargo/other dry cargo vessel	0	0	0	0	0
EGERSUND	**Tanker**	9	14	14	15	52
	Bulk vessel	12	3	1	5	21
	General cargo/other dry cargo vessel	107	129	118	111	465
STAVANGER	**Tanker**	113	136	139	134	522
	Bulk vessel	69	92	78	86	325
	General cargo/other dry cargo vessel	493	591	672	599	2355
SAUDA	**Tanker**	0	0	0	1	1
	Bulk vessel	9	13	13	10	45
	General cargo/other dry cargo vessel	59	63	68	66	256
HAUGESUND (KARMSUND)	**Tanker**	239	237	222	243	941
	Bulk vessel	104	90	90	147	431
	General cargo/other dry cargo vessel	761	897	876	910	3444
BERGEN AND OMLAND	**Tanker**	451	522	509	480	1962
	Bulk vessel	187	178	226	184	775
	General cargo/other dry cargo vessel	816	973	899	951	3639
FLORØ	**Tanker**	49	50	56	52	207
	Bulk vessel	101	105	97	119	422
	General cargo/other dry cargo vessel	284	310	401	299	1294
SVELGEN (BREMANGER)	**Tanker**	12	12	10	11	45
	Bulk vessel	11	15	14	10	50
	General cargo/other dry cargo vessel	79	67	77	80	303
MÅLØY (NORDFJORD)	**Tanker**	10	26	25	23	84
	Bulk vessel	35	36	34	27	132
	General cargo/other dry cargo vessel	206	232	216	224	878
ÅLESUND	**Tanker**	37	54	64	70	225
	Bulk vessel	36	47	48	64	195
	General cargo/other dry cargo vessel	540	565	518	593	2216
MOLDE	**Tanker**	48	62	59	58	227
	Bulk vessel	50	55	59	56	220
	General cargo/other dry cargo vessel	159	187	195	177	718
KRISTIANSUND	**Tanker**	102	109	153	179	543
	Bulk vessel	142	169	224	184	719
	General cargo/other dry cargo vessel	460	475	606	579	2120
TRONDHEIM	**Tanker**	40	43	69	71	223
	Bulk vessel	114	183	214	135	646

	General cargo/other dry cargo vessel	404	438	429	457	1728
BRØNNØYSUND (BRØNNØY)	Tanker	0	2	2	7	11
	Bulk vessel	53	57	45	43	198
	General cargo/other dry cargo vessel	22	33	36	37	128
HELGELAND HAVN	Tanker	21	22	25	24	92
	Bulk vessel	2	4	3	6	15
	General cargo/other dry cargo vessel	39	43	55	40	177
MO I RANA	Tanker	9	7	12	10	38
	Bulk vessel	29	19	23	26	97
	General cargo/other dry cargo vessel	150	170	161	151	632
TOTAL ARRIVALS		**9148**	**10047**	**10276**	**10293**	**39764**

TOTAL ARRIVALS BY SHIP TYPE	Bulk vessel	5104
	General cargo/ other dry cargo vessel	27237
	Tanker	7423

09518: MARITIME TRANSPORT STATISTICS. PORT CALLS BY PORT, TYPE OF VESSEL, FLAG, CONTENTS AND QUARTER (NORTHERN NORWAY)

PORTS IN SOUTHERN NORWAY	**Ship type**	**Arrivals of vessels**				
		2018 K1	**2018 K2**	**2018 K3**	**2018 K4**	**2018**
Bodø	**Tanker**	15	32	36	23	106
	Bulk vessel	51	84	92	83	310
	General cargo/other dry cargo vessel	134	190	252	210	786
Narvik	**Tanker**	2	7	6	5	20
	Bulk vessel	75	75	65	87	302
	General cargo/other dry cargo vessel	39	19	34	31	123
Harstad	**Tanker**	13	28	37	30	108
	Bulk vessel	15	61	42	34	152
	General cargo/other dry cargo vessel	114	128	193	158	593
Tromsø	**Tanker**	42	68	89	80	279
	Bulk vessel	35	65	91	71	262
	General cargo/other dry cargo vessel	329	404	455	412	1600
Hammerfest	**Tanker**	33	37	42	40	152

	Bulk vessel	10	40	11	47	108
	General cargo/other dry cargo vessel	104	117	119	126	466
Kirkenes	**Tanker**	6	6	5	6	23
	Bulk vessel	1	3	2	0	6
	General cargo/other dry cargo vessel	33	31	41	21	126
Sveagruva	**Tanker**	5	8	15	9	37
	Bulk vessel	2	1	7	0	10
	General cargo/other dry cargo vessel	7	21	18	20	66
TOTAL ARRIVALS		**1065**	**1425**	**1652**	**1493**	**5635**

TOTAL ARRIVALS BY SHIP TYPE	Bulk vessel	1150
	General cargo/other dry cargo vessel	3760
	Tanker	725

Reference:

STATISTICS NORWAY. 2018. *Maritime transport - 09518 Maritime transport statistics. Arrivals of vessels in domestics and foreign traffic, by type of vessel* [Online]. Statistics Norway. Available: https://www.ssb.no/en/statbank/list/havn/ [Accessed 20.04 2019].

Appendix 5: Query link - Marine shipping data in Southern Norway and Northern Norway

Query links for maritime shipping data from Statistics Norway (2018).

Southern Norway

Query link: http://www.ssb.no/en/statbank/sq/10023167/

Northern Norway and Finmark

Query link: http://www.ssb.no/en/statbank/sq/10023166/

Reference:

STATISTICS NORWAY. 2018. *Maritime transport - 09518 Maritime transport statistics. Arrivals of vessels in domestics and foreign traffic, by type of vessel* [Online]. Statistics Norway. Available: https://www.ssb.no/en/statbank/list/havn/ [Accessed 20.04 2019].

Appendix 6: Impact scores, effect factors and case study calculations

Impact scores are calculated by using the scoring system explained in section 3.4 in the present thesis, while EF and CF calculations are shown below and follows the method in chapter 4 about factor modelling.

1) Southern Norway (SN)

Invasive species in Southern Norway (SN)	Impact Score
Ciona intestinalis	0,85
Corethron criophilum	0,50
Coscinodiscus wailesii	0,35
Mya arenaria	0,78
Rhizosolenia indica	0,10
Salmacina dysteri	0,20
SUM impact scores	2,78
Number of native species	2007
Number of affected species	2
Number of alien species	6
Volume ballast water	$8{,}28E+09\ m^3$

Characterization factor:

$$CF_{SS} = FF_{SS} \times XF_{SS} \times EF_{SS}$$

$$CF_{SS} = \frac{N_{alien,SS}}{V_{SS}} \times \frac{\sum_s IS_{s,SS}}{N_{alien,SS}} \times \frac{N_{affected,SS}}{\frac{N_{native,SS}}{\sum_s IS_{s,SS}}}$$

$$= \frac{6}{8{,}28E+09\ m^3} \times \frac{2{,}78}{6} \times \frac{2}{\frac{2007}{2{,}78}}$$

$$= (7{,}25E-10)\frac{alien\ species}{m^3} \times 0{,}46 \times (2{,}77E-3)$$

$$= 9{,}30E-13\ \frac{PAF}{m^3}$$

Effect factor:

$$EF_{SS} = 8.28E+09\ \frac{PAF}{unit\ intensity}$$

2) Northern Norway and Finnmark (NN)

Northern Norway and Finnmark (NN)	**Impact score**
Coscinodiscus wailesii	0,35
Paralithodes camtschaticus	0,65
SUM impact scores	1
Number of native species	2102
Number of affected species	1
Number of alien species	2
Volume ballast water	7.6E+6

Characterization factor:

$$CF_{NN} = FF_{NN} \times XF_{NN} \times EF_{NN}$$

$$CF_{NN} = \frac{N_{alien,NN}}{V_{NN}} \times \frac{\sum_s IS_{s,NN}}{N_{alien,NN}} \times \frac{N_{affected,NN}}{\frac{N_{native,NN}}{\sum_s IS_{s,NN}}}$$

$$= \frac{2}{7.6\text{E+6}\ m^3} \times \frac{1}{2} \times \frac{1}{\frac{2102}{1}}$$

$$= (2.63E-7)\frac{alien\ species}{m^3} \times 0.5 \times (4.76E-4)\ PAF$$

$$= 6.23\text{E}-11\ \frac{PAF}{m^3}$$

Effect factor:

$$EF_{NN} = \frac{N_{affected,NN}}{\frac{N_{native,NN}}{\sum_s IS_{s,NN}}} = \frac{1}{\frac{2102}{1}} = 4.76E-4 = 0{,}0476\ \%$$

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