ALIEN SPECIES IN THE ARCTIC OCEAN

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This bachelor thesis marks the end of my career as an Aquatic Ecotechnology student. I therefore would like to close with a quote from my favourite book:

"So long, and thanks for all the fish."

- Douglas Adams, The Hitchhikers Guide to the Galaxy

ABSTRACT

The invasion of alien species threatens ecosystem functioning and is the second greatest cause for biodiversity loss around the world. Presently the Arctic regions are the least invaded realms of the world. However not much is known on the current- and future impact of alien species on the Arctic Ocean. An analysis of the already available literature on the subject of alien species in the Arctic Ocean could prove to be cost efficient. A confirmation of the usefulness of the available data means that there would be less need for field research when a literature research proves to be sufficient. Hence the European Commission initiated the Sea Basin Checkpoint (SBC) program to verify the feasibility of the available literature.

In order to gain a more in depth understanding of bottlenecks caused by alien species in the Arctic Ocean, and at the same time analyse the available data for its usefulness the eco-profile methodology was developed and applied.

Jassa marmorata was used as a sample-species to test the effectiveness of the eco-profile methodology at predicting the bottlenecks. The current- and future bottlenecks caused by the presence of *Jassa marmorata* were successfully determined, to the extent that it was possible to allocate 23 locations within the Arctic Ocean most susceptible to an invasion of *Jassa marmorata*. During the construction of the eco-profile it was found that the dataset on the species in the Arctic Ocean likely contained false information due to a sample contamination at the site of the investigation.

The testing of the eco-profile methodology indicated that it is not yet feasible to apply the method in its current state for the continuation of the SBC program. Some alterations have to be made to increase its efficiency and accuracy. Nevertheless it has proven to be a very useful method for assessing the quality of available literature on alien species in the Arctic Ocean, and at determining the current- and future bottlenecks of an alien species invasion.

1 INTRODUCTION

"Invasive alien species are the second largest threat to biological diversity after habitat destruction on continents, and the greatest cause of biodiversity loss on islands"

(Schei, 1996)

This quote was taken from the chairman's report of the Norway/UN Conference on alien species in 1996. It portrays the significant impact alien species can have on the native ecology at the site of introduction. Presently, the Polar Regions are the least invaded realms of the world by alien species (Molnar, Gamboa, Revenga, & Spalding, 2008). Low shipping intensity and extreme habitat conditions are important factors that result in this relative limited invasion. However, due to global warming and the melting of the Arctic sea ice, the North Pacific is becoming more connected to the North Atlantic Ocean. This results in new economic opportunities (e.g. shipping routes, sea mining) but also more temperate living conditions for Marine Species. With these changes, the risk of introducing alien species in the Arctic Ocean increases. The rapid changes in the Arctic marine ecosystems related to climate change make the system vulnerable to invasive alien species (Norden, 2014). Marine alien species can cause harm to native species, ecosystems and animal health, as well as pose a threat to public health, safety and economy (Crowl, Crist, R, Belovsky, & Lugo, 2008; Pimentel, Zuniga, & Morrison, 2005; Vander Zanden, Casselman, & Rasmussen, 1999). According to Gause's competitive exclusion principle; *"two species competing for the same resource cannot coexist at constant population values"* (Gause, 1934). It is therefore necessary to establish where a base for competition could exist between the species in order to determine the effects to the native ecology. The method for doing this is by creating detailed eco-profiles on each alien species. These eco-profiles contain information such as: invasion pathways, feeding habits, habitat requirements, etc. Particularly important factors within the eco-profile are: temperature related factors and growth. With the help of the eco-profiles it is possible to identify possible common niches between alien- and native species, thus also predict future ecological bottleneck situations.

The goal of this thesis is to set-up and analyse the effectiveness of the eco-profile methodology for predicting the future *bottlenecks* to native ecology of an alien species invasion (Please consult the glossary at the end of the report for the definition of terms used during this thesis). The methodology is tested by applying it to a selection of alien species that are present in the Arctic Ocean. Additionally, the data sources used during the literature research are analysed for their usefulness to the current study, and future studies.

1.1 Organizational structure of the research

The alien species research is part of the Arctic Sea-Basin Checkpoints (SBC) program. This program was commissioned by the European Commission Directorate-General for Maritime Affairs and Fisheries (Henceforth: EC). The EC is aware of the large quantities of information gathered in various data sources. Due to the large quantities of information already gathered in previous studies, there is bound to be recurrence of data. Their question is; how reliable, or correct, is information from the data sources, and could this data be used to find the answers to research questions of future studies? If the results from the SBC program indicate that the readily available data is in fact correct, and then there would be no need to re-acquire said data because a literature research would suffice, thus the costs of a study would decrease.

The execution of the project is a collaborative effort by Arcadis –Netherlands / -U.S.A. / -Canada, IMARES, SINTEF and MARIS. The goal of the project is to determine the relevance and usefulness of the available data. This is achieved by setting *challenges*, in which concrete questions on different subjects need to be answered. If a certain challenge cannot be met by means of consulting the available databases, then the conclusion will be that the current available data on that subject is not complete and therefore not useful. There are a total of 11 SBC challenges; [Appendix 1] shows the challenge-leaders for each of the subjects and the organizational division of the project.

2 THEORETICAL FRAMEWORK

2.1 The Arctic Ocean (Area of Research)

The Arctic Ocean is located in the Northern Hemisphere and part of the Artic North Polar Region [Fig.1]. It is the smallest of the world's five oceans and by some oceanographers even considered as an Arctic Mediterranean Sea (Briggs & Smithson, 1985). Over the year much of its surface is covered by ice, and almost entirely during winter. However, the ice coverage is diminishing due to global warming causing the ice to melt more rapidly. The seasonal pack ice, which is the ice that is not attached to any land and mobile in its nature ("Pack Ice," 2016), is of great importance to the abundance of krill. Its disappearance could result in a serious decline in Krill populations, which are the backbone of the Arctic food chain (Gross, 2005a). Additionally, the disappearance of the pack ice could in the future, open up the area for new shipping routes and other economic activities such as off-shore drilling operations (Bast, Makhijani, Pickard, & Whitley, 2014). This new influx of human activity into an area that was previously relatively unscathed by anthropogenic activities could create great problems to the increasingly fragile ecosystem in the Arctic Ocean (Gross, 2005b).

Fig. 1: The Arctic region; of note, the region's southerly border on this map is depicted by a red isotherm, with all territory to the north having an average temperature of less than 10 °C (50 °F) in July. (Courtesy of the: Central Intelligence Agency's World)

2.2 Defining the concept of Alien Invasive Species (AIS)

It is necessary to prevent confusion on the definition of concepts such as “Alien” and “Invasive”. There are many varying views on when a species qualifies as Alien or if it is viewed as a native species. Alien; Exotic; Non-indigenous; Imported; Introduced; Immigrant; Colonizer; Naturalized, are all terms used to describe invasive species in the field of invasion ecology (Valéry, Fritz, Lefeuvre, & Simberloff, 2008). The dissension between invasion biologists is clearly revealed in this profusion of different terms that are almost identical in meaning. The contrast in opinions on defining the concept of alien versus native and non-invasive versus invasive stems from the current use of two different main criteria: Geographic- and Impact criterion (Valéry et al., 2008).

2.2.1 The Geographical Criterion

The geographical criterion defines a species as *alien* when it has moved from its original habitat or ecosystem (A), to a new habitat or ecosystem where it has not settled before (B) (Valéry et al., 2008). This relocation to a new habitat can happen either passively (e.g., via ballast water or ship hull fouling) or actively (e.g., through natural spread or intentional introduction into the area). Some researchers claim that a species is to be considered alien, only when it has overcome a major geographical barrier. This barrier can be measured in distance (i.e., greater than 100km), or as a major natural obstacle such as a mountain range or a previously secluded lake (Richardson et al., 2000).

2.2.2 The Impact Criterion

(Davis & Thompson, 2000) state the Geographical criterion alone does not allow for native invasive species to be considered into the assessment. They propose that species that colonize and dominate a new adjacent or nearby habitat through diffusion dispersal, also qualify as invasive. It is therefore necessary to include the impact criterion into the Alien Invasive Species (AIS) concept as well.

The Impact criterion defines a species as *invasive* when it colonizes and dominates a new habitat or niche. Some researchers believe that the impact of a species on the community/ecosystem in which it invades has to be of a significant magnitude in order for it to be considered invasive (Davis & Thompson, 2000; Inderjit, 2005). However, the significance of a magnitude is very difficult to assess and propagates room for interpretation (ESA, 2001; Richardson et al., 2000). This is generally not a desired situation as it allows for too many uncertainties to properly conduct an impact assessment (Valéry et al., 2008). Valéry et al. (2008) further exemplifies the importance of distinguishing a primary phenomenon from the impact by discussing the use of the Richter scale on defining the magnitude of an earthquake. The impact of an earthquake may vary considerately depending on fixed factors (Gautier, 1975; ROTHE, 1977) (e.g., population density or nearness to the epicentre); much like the impact of an invasive species on a community or ecosystem may vary greatly. The impact of an invasive species is often determined by the superiority of the invasive species' response after its introduction to- or change of a community or ecosystem. This response is influenced by two major factors that vary in many situations: (1) the match between its traits and those of the other species belonging to the same functional group (Dukes & Mooney, 2004; Grime, 1998; Strauss, Webb, & Salamin, 2006) and (2), the new relationships established between it and all species in its environment (Valéry et al., 2008)). Unfortunately, a measurement tool such as the Richter scale has thus far not been created for quantifying the "extent of the impact" of invasive species on a community or ecosystem, thus making it difficult to quantify this phenomenon (Parker, I.M., Simberloff, D., Lonsdale, W.M., Goodell, K., Wonham, M., Kareiva, P.M., Williamson, M.H., Holle, B. von, Moyle, P.B., Byers, J.E., Goldwasser, 1999).

However research has suggested that it is possible to identify a primary phenomenon associated with biological invasion by a species, thus assessing the magnitude of the impact. Valéry et al. (2008) explain that a biological invasion always appears in the course of an interspecific competition, which is a form of competition where different species compete for the same recourses (Tilman, 1987). In this respect, the interspecific competition can be considered to be the primary phenomenon (or origin) of the biological invasion. This statement is further reinforced by theoretical models constructed by both (Davis & Thompson, 2000; and Tilman, 1999). It is also perfectly illustrated in the numerical *Threat Scoring System* [Appendix 2] applied by (Molnar et al., 2008) during their research.

2.2.3 Definition of AIS

The goal of this chapter was to construct an encompassing definition for the concept of *Alien Invasive Species* that can be applied throughout the rest of the thesis by Hahn L. (2016) on a*lien species in the Arctic Ocean.* Based on the information gathered during the literature research the following groups of invasive and/or alien species have been determined to be either relevant (Yes) or not relevant (No) to the research, see [Table 1].

Table 1: groups of invasive and/or alien species

Group	Description	Relevance
1.	Alien species that are invasive	Yes
2.	Alien species that are not invasive but are capable of sustaining a symbiotic relationship with the native species or inhabit a free niche in the area.	Yes
3.	Alien species that are not invasive and are incapable of sustaining a symbiotic relationship with the native species or inhabit a free niche in the area.	No
4.	Native species that are invasive	No

In conclusion, an alien species is one that inhabits a community or ecosystem it has previously never inhabited before (Richardson et al., 2000; Valéry et al., 2008). An invasive species inhabits a new community or ecosystem but out-competes native species (of the same functional group) for a niche position in that area (Davis & Thompson, 2000; Inderjit, 2005). Invasive species do not per definition have to be alien species and can be original inhabitants of the native ecosystem.

The relevance of these groups is based on the main goal of the research: to assess current and future bottleneck situations for a selection of alien species to the native ecology of the Arctic Ocean. Group 3 isn't relevant for this thesis because an alien species that is unable to share or inhabit a niche will most likely not be able to sustain itself in that environment for a longer period of time and subsequently be removed. Group 4 isn't relevant to the research because it does not include the aspect of alien species.

Based on the factors discussed in the chapter above, the following definition for alien invasive species is proposed:

"A species that inhibits a community or ecosystem it has previously never inhabited before following the disappearance of a (natural) obstacle, giving it a competitive advantage over native species, which allows it to spread rapidly and to conquer novel areas with recipient ecosystems in which it can become a dominant population"

The concept of alien invasive species will henceforth be regarded with the definition proposed above. It is however imperative to mention that the previously mentioned group division of alien/invasive species in Table 1 will also be used as a criterion to determine the relevance of any acquired data for this particular research.

2.3 Alien species

In this thesis, the criterion used for defining an "alien species" is the Geographical Criterion. A species is defined as "alien" when it has moved from its original habitat or ecosystem (A), to a new habitat or ecosystem where it has not settled before (B). Marine alien species can be found all over the globe and can cause serious problems such as harming native species, harming ecosystems and harming animal health, as well as pose a threat to public health, safety and economy (Crowl et al., 2008; Pimentel et al., 2005; Vander Zanden et al., 1999). Currently the Arctic Ocean is the least invaded realm in the world (Molnar et al., 2008). However, a number of alien species have already been reported in the Arctic Ocean, such as the king crab and the snow crab, as well as various species of microalgae, macro algae, molluscs and fish. alien species can pose a serious threat to the marine ecosystem by outcompeting the native species, or changing the characteristics of its natural surroundings and reduce overall biodiversity (Jousson et al., 2000). Because of this threat, they have been included in the European Marine Strategy Framework Directive (Descriptor 2: "Non-Indigenous Species introduced by human activities are at levels that do not adversely alter the ecosystem") and are a focus point for many different organizations and governments (Freire-Gibb, Koss, Margonski, & Papadopoulou, 2014)

2.4 Impacts of Alien Species

(Katsanevakis et al., 2014) provide several key impacts associated with alien species on ecosystem functioning. Ecosystem impacts include impact on: single or multiple other species, keystone species or species of high conservation value, entire ecosystem processes/wider ecosystem functioning, or impacts on habitats as ecosystem engineers/creators of novel habitats. Additionally alien species can also have an impact on economic activities due to the undeniable connection between ecosystem functioning and anthropogenic activities. Economic activities that can be impacted include cultural activities such as recreation and tourism and provisioning activities such as fisheries or aquaculture. A well-known example is the rapid expansion of the introduced Pacific oyster *Crassostrea gigas* (Thunberg, 1793) throughout receiving ecosystems within NW European estuaries. There are cases where the Pacific oyster has colonized stretches of beach that are now no longer accessible for cultural activities because of their sharp shells that can cut peoples feet (Troost, 2010). Impacts to industrial facilities can also occur, especially those using once-through-cooling water withdrawals. Invasive (shellfish) species may cause clogging in pipes of industrial facilities requiring use of chemical treatments or other mitigation strategies.

2.5 Invasion pathways

(Minchin, Gollasch, Cohen, Hewitt, & Olenin, 2009) define two types of marine introductions; Primary, -and Secondary introductions. A primary introduction is defined as a non-native species introduced into a new area directly from its native region. A secondary invasion is after a species has been introduced into a new area and spreads (or diffuses) from the site of introduction to neighbouring recipient ecosystems.

The (European Environment Agency, 2013) identifies four primary pathways of introduction for marine alien species; leakage from aquaculture facilities, corridors serving as stepping stones which connect one ecosystem to the other , accidental escape from aquarium trade, and shipping. The latter is generally considered to be the transport vector with the greatest impact to ecology. Marine organisms either attach themselves to the exterior of ships or are taken up into the ballast water tanks. Via this route they can travel great distances and invade habitats that would otherwise have been impossible to reach in natural conditions due to the presence of natural barriers (e.g. great distance/ no connective waters between native habitat and point of introduction). An evaluation by the (European Environment Agency, 2013) on global shipping traffic revealed that more than 480 000 annual ship movements occur worldwide, each with the potential of transporting organisms over great distances. Estimates by (Gollasch, 2010) indicate shipping and its associated vectors (ballast tanks, hulls, anchor chains, and sea chests) may carry 4000 to 7000 taxa each day. This number is likely to increase when taking into consideration the expanding global trade, global warming, and the re-use of novel trade routes. A good example is the Northwest Passage connecting the Atlantic and Pacific oceans which has been sufficiently ice-free since the summer of 2007, shortening the path between the two oceans, and subsequently increasing the chances of an introduction of alien species (Susan L. Williams, Ian C. Davidson & Zabin, 2015).

2.6 Objective

The main objective of this final thesis is to gain a more in depth understanding of bottlenecks caused by alien species in the Arctic Ocean, and at the same time analyse the available data for its usefulness. The eco-profile methodology was developed during this thesis as a tool that would allow for these objectives to be achieved. The eco-profile will be analysed for its effectiveness and applicability to the current study, and future studies

2.6.1 Products

- The eco-profile methodology
- An assessment on the effectiveness of the eco-profile methodology
- A prediction on future bottlenecks caused by the presence of an alien species in the Arctic Ocean.
- An assessment on the usefulness of the data sources on the subject of alien species in the Arctic Ocean.

2.7 Research Questions

Based on the information gathered thus far on the subject of alien species, and the research questions already formulated by Kater B. & Hahn L. (2016), the following research questions have been determined to be relevant:

Research question: To what extend is the use of the eco-profile methodology feasible for the continuation of the Sea Basin Checkpoint program?

Sub questions:

- How effective is the eco-profile methodology in prediction the bottlenecks of an alien species invasion?
- How effective is the eco-profile methodology as a tool for analysing the usefulness of the data sources for future studies?

3 METHOD

3.1 The Eco-profile

The eco-profile was developed at the beginning of this research with the purpose of predicting where future ecological invasions of the alien species may occur, while simultaneously analysing the available data for its usefulness to future studies. The reason for developing my own methodology is because it was found that a method addressing both alien species research as well as data analysis did not yet exist. Each column represents the subject of the criteria that are listed below [see table 2]. These criteria were theorized after a literature research on the components that affect a species' invasion success and capabilities, and consultation with invasion ecologist. Part of the eco-profile is pairing the information with geographical data on: shipping routes, ocean currents and the Arctic Ocean's current and future predicted oceanic temperature. Coupling this information will yield in a better understanding of the area wide processes of the Arctic Ocean current and aids in the determination of possible current- and future *"bottleneck situations"*.

Table 2: Data content of an Eco-profile

Eco-profile

Species information	**Habitat characteristics**	**Invasion**	**Chances and threats**
Appearances	Population characteristics	Primary transport vectors	Chances
Life cycle	Tolerance	Invasion history of the Arctic Ocean	Threats
Feeding habits	Native habitat	Future invasion pathways	

Finding the future bottlenecks

Impacts	locations

Conclusion

3.1.1 Analysing the eco-profile methodology

The components that should comprise the eco-profile were theorized at the start of the thesis based on their expected influence on an alien species' invasion potential. However these components might prove to not be relevant to an alien species' invasion potential in practice. Much like any theoretical model; it might look good on paper, but does it actually work? It is for this reason that an alien species (in this case: *Jassa marmorata*) was inserted into the eco-profile; essentially, putting theory into practice.

The following method was applied only after the eco-profile methodology had been constructed. To verify if the theorized relevant components of the ecoprofile determined at the beginning of the thesis were sound, or if they should be excluded in the future. And to ascertain the quality of the data used for each component. See step 1 to 3:

1. Recapitulate the main point of the content of each component (i.e. the part most relevant to the alien species' invasion potential); insert this information into Table 3.

2. Assess the relevance of each component for determining the invasion potential of the species, and the quality of the data that required going into each component of the eco-profile by inserting the rating system into Table 3.

   Rating system for relevance of the eco-profile components:

   -1: Not relevant for determining the invasion potential of an alien species

   0: Impartial information for determining the invasion potential of the alien species

   1: Relevant for determining the invasion potential of an alien species

   Rating system for quality of the data:

   -1: The available data required for the component of the eco-profile is incorrect

   0: The data required for the component of the eco-profile is missing

   1: The available data required for the component of the eco-profile is correct

Table 3: Layout of the rating system (Blank)

	Recapitulation of content	Relevance score (R)	Quality score (Q)
Component name*			

This is for testing the eco-profile

This is for testing the data

3. Import the rating system results into Table 4. The table serves as a tool that shows clearly which components of the eco-profile might need to be revised and which data is lacking or is of bad quality. If a component is rated with R: -1, than this component is up for consideration to be excluded from the eco-profile. R: 0 means that the component in question is not relevant to the alien species currently under investigation (*Jassa marmorata)* but it might still be relevant for a different alien species.

Table 4: The eco-profile with the scoring system incorporated (Blank)

Species information	**R**	**Q**	**Habitat characteristics**	**R**	**Q**	**Invasion**	**R**	**Q**	**Chances and threats**	**R**	**Q**
Appearances			Population characteristics			Primary transport vectors			Chances		
Life cycle			Tolerance			Future invasion pathways			Threats		
Feeding habits			Native habitat			Invasion history of the Arctic Ocean					

Essentially, the question opted in step 2 with regards to the relevance of the components is: "Is this information necessary for determining the invasion potential of an alien species?" This is the same question that was asked when the eco-profile was being constructed at the beginning of the thesis. The difference however, is the 2nd time this question is asked is after the eco-profile has been extensively used and tested (trial and error). Asking this question for again will indicate if the theory matches the practice. You can build a car, but only after you've driven it will you know if it works properly.

3.2 Literature research

Literature research is the cornerstone of this thesis. Almost all of the data that is going to be applied during the final thesis project will be acquired through information databases that are specific for the Arctic Ocean or alien species. It is not only the goal to collect data on these subjects, but also to analyse the quality of the data.

3.3 Expert knowledge

In addition to the individual literature research, consulting experts in the area of aquatic invasive species is a key part of the research method. Arcadis has no shortage in experts on the area of marine ecology. During the final thesis project, there will be a close cooperation with the experts associated with the SBC research. Each person is an expert in their own respectable field:

- Dr. Ir. Jeroen Wijsman (Marine ecology and invasive species expert)
- Andrea Sneekes (Ballast water and invasive species, IMARES)
- Belinda Kater (Senior marine ecologist, ARCADIS NL)
- Dr. Paul Patrick (Invasive species life history and industrial impacts)

Aside from the experts mentioned above, consultation with external experts will be a key factor during the research.

3.4 Species selection criteria

The selected species are mere samples that are used to test the quality of information available on the species, as well as the effectiveness of the developed methodology for determining the bottlenecks. The selection is therefore done, to a certain degree; randomly. However, there are certain criteria that confine the final selection, listed below.

1. <u>Occurrences of the selected alien species must have already been present in the Arctic Ocean at the time of the start of this thesis.</u> This prevents the researcher from focussing on alien species that are not present in the Arctic Ocean.

2. <u>A species of which the future spread and effects have already been thoroughly investigated will not be included in the selection process.</u> Research from previous studies should not be repeated (e.g. There are, many studies on the spread and effects the Red King Crab. Additional research on this alien species will less likely yield any new meaningful results.).

4 RESULTS FROM THE ECO-PROFILE

4.1 Selected alien species

Based on the species selection criteria described in paragraph 3.4 the species *Jassa marmorata* (Holmes, 1903) was selected as an alien species fit for testing the eco-profile methodology. An initial literature research indicated a presence of *Jassa marmorata* in the Arctic Ocean (GBIF Secretariat, 2016), but the current knowledge on the future spread and impact of *Jassa marmorata* was limited, therefore to study this species was more likely to yield meaningful results.

4.2 Species information

4.2.1 Appearances

Jassa marmorata is a tube-dwelling amphipod species with a size up to 10 mm [Picture 1]. They have large rounded eyes that are located entirely or partially within the lateral lobe of the head and two large antennas that are approximately one-half the body length or greater. They commonly have a greyish colour with distinct reddish brown markings. There is a distinct sexual dimorphism amongst the *J. marmorata* species: only males present an enlarged propodus, or “thumb” on their second gnathopods, or “appendage” and they are generally bigger in size than their female counter parts. Additionally, males come in two forms: "major" and "minor". Minors and females are approximately the same size, while majors are about twice as big and have an enlarged “thumb.” The thumb develops only after the last molt (Beermann, 2013; Mori, Cerrano, Scinto, & Benvenuto, 2007).

Picture 1: : An adult major male Jassa marmorata (Image courtesy of Adriana Radulovici, Biodiversity Institute of Ontario via boldsystems.org and the CC BY-NC-SA 3.0 license)

4.2.2 Life cycle

The life cycle of an amphipod is significantly influenced by temperature and temperature related factors (e.g. abundancy of food) (Wilson & Parker, 1996).

4.2.2.1 Temperature and growth

Research done by (Mori et al., 2007) towards the seasonal cycle of *J. marmorata* in Italian waters found that an increase in female mean body size occurs during the cold seasons. This finding is in line with the data provided by (Franz & Mohamed, 1989) who found that: females are larger in winter and spring, indicating that areas with lower water temperatures produce larger female *Jassa marmorata.* No information has indicated that low water temperature has the same effect on male *Jassa marmorata* size as it has on females. Males do not live as long as females but attain greater size by growing faster through fewer molts (Prince William Sound Regional Citizens' Advisory Council, 2004). The life span of *Jassa marmorata* generally amounts to less than a year (Hill, 2000). There is no known data on the effects of temperature on the longevity of *Jassa marmorata.*

4.2.2.2 Temperature and reproduction

The increase in female body size attained in response to lower water temperatures is positively correlated with egg production (Mori et al., 2007). The relation between temperature and an increase in the number of juveniles is shown in Appendix 3. During the research of Mori et al, (2007) in Italian waters it was found that females are more fertile in colder waters with a mean production of 32-44 embryos per female versus 16-20 embryos in the warmer months of the year. However, during research by (Beerman & Purz, 2013) in the German Ocean it was found that the fecundity per female *Jassa marmorata* is between 125-175 eggs per hatch . These variations in number of embryos produced are most likely caused by the difference in water temperature of the two research locations. It has therefore been difficult to ascertain a reliable mean on the production of embryos for *Jassa marmorata*. However, (Hill, 2000) states that the mean number of eggs per female is around 11-100 for the species *Jassa falcata (Montagu, 1808);* a closely related species which *J. marmorata* has often been misidentified as. Due to their close relation and often interchangeable characteristics it is acceptable to use the data on *J. falcata* to describe some aspects of *Jassa marmoratas'* life cycle.

4.2.2.3 Reproductive behavior

Mature males generally only abandon their residential tubes when in search of receptive females to mate with, after which they guard the female from other competitive males (Mori et al., 2007). The mating system is polygynous: the females lay eggs inside their tubes after which they can each be potentially fertilized by a different male (Hill, 2000). The major form males display a more aggressive method of mating as opposed to the minor form males who exhibit a 'sneak-tactic' where they shrewdly enter a tube to fertilize the eggs (Fofonoff, Ruiz, Steves, & Carlton, 2003). This also explains why some males have the urge to guard receptive females prior to copulation in order to secure as many of the females' eggs for that specific male. Female *Jassa marmorata* spend the entirety of their life within their own tubes, where they feed, mate, and tend to their young. Much like many other crustaceans, females are only fertile for a few hours after molting (Mori et al., 2007). However production of gametes occurs all throughout the year, thus ensuring that the possibility to reproduce is present after each molt (Nair & Anger, 1979).

4.2.3 Feeding habits

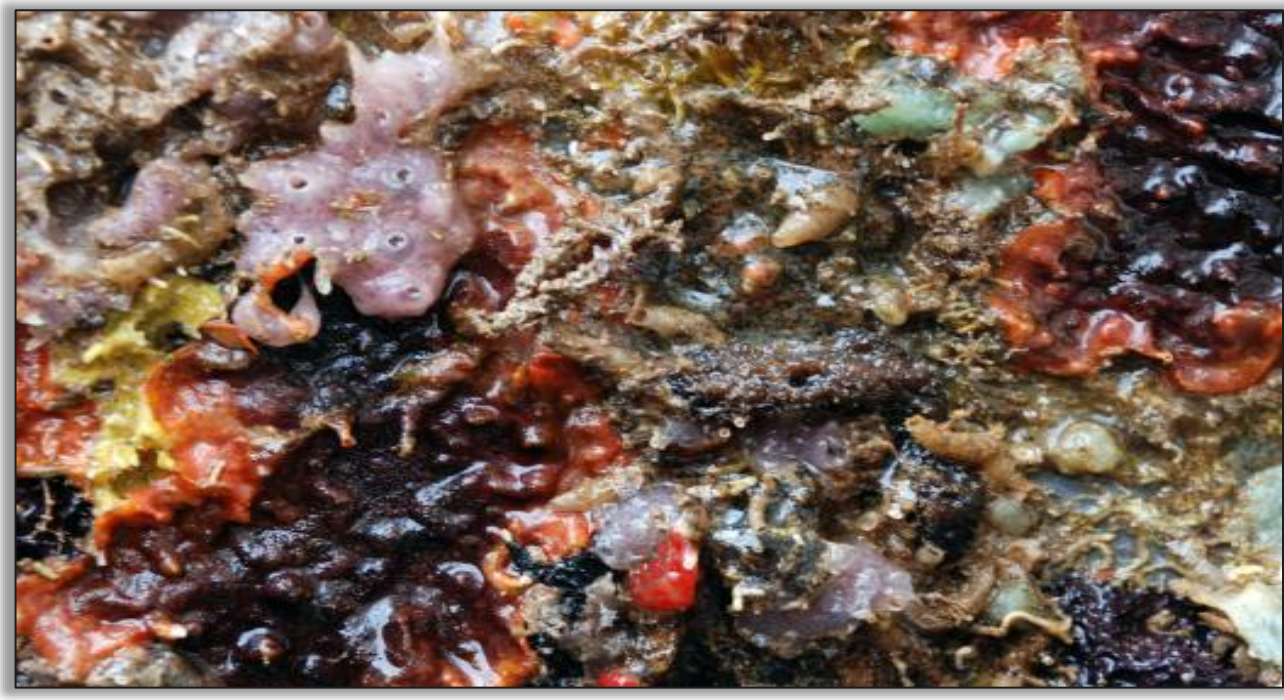
Jassa marmorata feeds by constructing cylindrical tubes- out of 'amphipod silk' and incorporating detritus and algae fragments into the structure, see [Picture 2]. They then occupy these tubes and use various 'limbs' to extract plankton, detritus and other materials from the passing water currents, either passively or actively (Dixon & Moore, 1997). Research by (Beermann, 2013; Borowsky, 1985; Schückel, Schückel, Beck, & Liebezeit, 2010) has shown that *J. marmorata* was significantly more abundant at an exposed rather than sheltered location, and has a preference for more turbulent and fast flowing waters. This preferred settling location may be due to the stronger currents which provide an increased supply of food and an increased rate of colonization. This is in line with the predominant locations in which *J. marmorata* habitats are found, such as rocks, oyster reefs, eelgrass beds, marinas, docks, buoys, jetties, shipwrecks and ships' hulls (Benson, Brining, & Perrin, 1973; Bousfield, 1965; Franz & Mohamed, 1989). The main predators of *J. marmorata* are shrimp, crabs and fishes (Fofonoff et al., 2003).

Picture 2: Jassa marmorata *feeding from their cylindrical tubes constructed out of detritus and amphipod silk. (Image courtesy of: Keith Hiscock (published on the MarLIN website))*

4.3 Habitat characteristics

4.3.1 The fouling community

Jassa marmorata can form dense tube colonies on hard substrata. Here they can co-occur with other macro-algae, and are often dominant and important members of “fouling communities” (Karez & Ludynia, 2003). Fouling communities are an assemblage of animals (mostly barnacle species) and plants which grow on hard substrates, see [picture 3] (Benson et al., 1973). Fouling is a natural biological phenomenon practiced mostly by attached or sessile animals (e.g.: mussels) in shallower water. However problems can arise by settlement of *Jassa marmorata*. *Jassa* species have been known to form their colonies in the warm water discharge pipes from power stations, which can lead to obstruction of the flow through the pipe (Gaston, Fish, & Fish, 1997).



Picture 3: A fouling community is an assemblage of various plants and animals attached to artificial structures (Image courtesy of: Marinelizard, 2012, published on: marinelizard.wordpress.com)

4.3.2 Tolerance

The tolerance range that an Alien Invasive Species has can give an indication on the expected "success" of its biological invasion. A species with a high tolerance to varying habitat characteristics is able to potentially settle in a greater multitude of areas. [Table 5] shows the tolerance range of *J. marmorata* to various habitat characteristics.

Table 5: Tolerance range of *Jassa marmorata*

	Tolerance range	**Source**
Temperature (ºC)	(min): -2 / (max): 27	(Fofonoff et al., 2003)
Salinity (PSU)	(min): 12 / (max): 38	(Bay et al., 2001)
Substrate	Only hard substrata	See paragraph 4.2.1
Depth (m)	(min): 0 / (max): 5	(Encyclopedia of Life, 2005)
Tidal	Subtidal / Low intertidal	(Fofonoff et al., 2003)

4.3.3 Native habitats

Due to *Jassa marmoratas'* extreme dimorphism it has historically been misidentified as *Jassa falcata*. Reports of *J. falcata* from around the world have been found to refer to *J. marmorata*. In many cases it was the presence of similar species that has complicated determining the range of *J. marmorata* (Conlan, 1990). Because of this it has been difficult for researchers to pinpoint the native habitat of *J. marmorata.*

Fortunately, (Fofonoff et al., 2003) have constructed a map [see Appendix 4] that shows the "Cryptogenic" range of *J. marmorata*. Meaning: "of obscure or unknown origin" (Dictionary.com, n.d.). The map was created by compiling the data from various researches in order to achieve an estimate of the global distribution of *J. marmorata.* As can be seen from the picture, there is no known native habitat for *J. marmorata*. The yellow indicates the cryptogenic habitats of the species; red indicates where introduction of the species has been reported. From this we see that the distribution of *J. marmorata* is global.

4.4 Invasion

4.4.1 Primary transport vectors

In natural conditions *Jassa marmorata* only partakes in short-distance dispersal during its juvenile stage. Adults- once settled into an area, tend to remain local at the site of inoculation (de Kluijver & Ingalsuo, 2010; Molnar et al., 2008). For this reason it is assumed the global dispersal of *Jassa marmorata* is caused by a non-natural phenomenon.

Ship hull fouling and ballast water are the two main transport vectors associated with dispersal of *Jassa marmorata*(National Park Service, 2009).

Ship hull fouling: A possible explanation for why this transport vector is associated with the spread of *Jassa marmorata* is the preferred habitat characteristics of a fouling community. Fouling communities attach themselves to hard surfaces in the upper 5 meters of the water column. Preferably with a continuous flow of water that provides inflow of food (Fofonoff et al., 2003). This makes the hull of a ship an ideal location for *Jassa marmorata* to settle.

Ballast water: Many *Jassa marmorata* habitats can be found in harbors. The ships in these harbors take up ballast water and can unintentionally take up juvenile *Jassa marmorata* into the ballast tank. When they discharge the ballast water upon arrival at the other harbor the non-native species is introduced into the area (Fallis, 2013). Crustacea are the most successful phylum for introduction in marine systems due to several distinct characteristics. Their small size, morphology, and tolerance for wide ranges in salinity and temperature enhance their ability to survive introduction into new areas. In addition to this, their exoskeleton increases their chances of surviving the pressures caused by the uptake and transport of ballast water (Ashton, Willis, Cook, & Burrows, 2007).

4.4.2 Future invasion pathways

Global warming will have an effect on the shipping routes through the Arctic Ocean. Due to the increasing temperatures more ice will melt. This has already resulted in the “opening up’’ of some navigational routes that were previously non-existent or only available during short periods in the summer. The Northwest Passage connecting the Atlantic and Pacific oceans has been sufficiently ice-free since the summer of 2007, shortening the path between the two oceans and subsequently increasing the chances of an introduction of alien species (Susan L. Williams, Ian C. Davidson & Zabin, 2015). This can be seen in [Appendix 6 and 7] which show an unmistakable decline in sea ice coverage in summer from 1984 to 2012. An increase in shipping means an increase of opportunities for alien species to be introduced into a new habitat.

4.4.3 Invasion history of the Arctic Ocean

There are two known datasets that include reported occurrences of *Jassa marmorata* in the Arctic Ocean. The “(Table 2a and b) Median abundances of Macrobenthos in surface sediments”, provided by (Kröncke, 1994) who, in 1991, conducted a maritime expedition to assess the Macrobenthos composition, abundance and biomass in the Arctic Ocean; And the “Arctic Ocean Diversity” dataset provided by the (Alaska Ocean Observing System, 1991) (henceforth: AOOS).The two datasets each contain a total number of 61 occurrences of *Jassa marmorata* within the Arctic Ocean (GBIF.org, n.d.). See [Appendix 5] for the locations of the occurrences in the Arctic Ocean.

However, concerns have been raised regarding the reliability of the data submitted by Kröncke from the maritime expedition of 1991. During the expedition macrofauna was sampled at 30 stations, at depths of 1018-4478 m. A total of 42 species were found, of which *Jassa marmorata* was the most common species (Kröncke, 1994). However, Russian colleagues of Kröncke have remarked that it is highly unlikely that *Jassa marmorata* was found in such deep water because it is not in accordance with their general habitat preference. This statement is revalidated when looking at paragraph 4.3.2; *Jassa marmorata* lives at a maximum depth of 5 meters (Encyclopedia of Life, 2005). They have proposed a more probable cause for the high number of *Jassa marmorata* occurrences, which is that the species had (perhaps beforehand) taken up residence inside the rinsing water pump system of the Polarstern (the German polar research vessel used by Kröncke Ingrid during the expedition (Alfred Wegener Institut, 2016)). The equipment used on the boat may have been “contaminated” with *Jassa* marmorata, and could have affected the outcome of the measurements, making it impossible to verify the accuracy of the data. For this reason the occurrences reported by Kröncke aren't used for this study.

On the GBIF website the dataset from the AOOS gives 61 occurrences of *Jassa marmorata* in the Arctic Ocean. On the GBIF website it is shown that these samples were taken at depths between 0 and 5 meters. However, when this data was imported into QGIS it showed that the occurrences data was collected at stations where the highest point of the ocean floor is several hundreds of meters below sea level (NOAA, 2007). As stated before, *Jassa marmorata* lives in fouling communities on hard substrates in the upper 5 meters of the water column, and it does not partake in natural long distance migration. When taking these characteristics of *Jassa marmorata* into consideration it is justifiable to theorize that these occurrences data are incorrect. Additionally, the occurrences from the AOOC dataset are from the same year as the maritime expedition by Kröncke in 1991 and they are also found at similar locations as the sample collection sites. An inquiry towards the data provider of the "Arctic Ocean Diversity" dataset has confirmed that the original source for this dataset is in fact derived from the dataset compiled by Kröncke during her 1991 benthic species research. It is for this reason that the "Arctic Ocean Diversity" is also considered unreliable and is thus not included in this study.

Considering that the only two known datasets on *Jassa marmorata* occurrences in the Arctic Ocean are deemed not reliable enough to be included into this report, it can be said that there is no longer any defining proof of an invasion of this species in the Arctic Ocean.

However, from these findings it is now clear that *Jassa marmorata* can survive the transport into and conditions of the Arctic Ocean, and already has done so in 1991. Therefore, it is reasonable to theorize that it could have invaded some coastal areas in the Arctic Ocean. The expected current invasion of *Jassa marmorata* in the Arctic Ocean is discussed further in paragraph: 4.6.1.

4.5 Chances and threats

4.5.1 Chances

J. marmorata is an important food source for shrimps, fishes and crabs (Bousfield, 1965), introduction of the fast growing AIS could provide an increase in food availability for predators. Research by (Schückel et al., 2010) suggest that the extensive mud-tube colonies of *J. marmorata* that form in fouling communities and on various substrates provide suitable habitat for *Caprella mutica* (Schückel et al., 2010) which is also an invasive species that has been reported to be present in the Arctic Ocean (Buschbaum & Gutow, 2005). This could mean that settlement of *J. marmorata* in the Arctic Ocean can aid in the settlement of other invasive species in that area. Additionally *Jassa marmoratas*' ability to form symbiotic relations with other species could be an asset to its survival (and in extension its distribution), but a possible threat to native species. The rapid expansion of *Jassa marmorata* communities could be a contributing factor to the take-over of space and resources of native species.

This may suggest that *Jassa marmorata* is a species able to adequately adapt to changes in its environment and live in a symbiotic relationship with other marine species, thus making it a possible successful invader of novel areas.

4.5.2 Threats

Studies have shown that amphipods, such as *J. marmorata* play important roles in determining the type and distribution of algal communities, particularly where predation is low (Prince William Sound Regional Citizens' Advisory Council, 2004). Unfortunately the exact effects of the amphipod on the algae are not described. The fast growing dense masses of tubes constructed out of sediment by *Jassa marmorata* may discourage settlement of boring organisms (e.g. molluscs, phoronids) (Fofonoff et al., 2003). Boring organism can do great damage to submerged structures. They execute a form of bioerosion where they settle on hard substrates and compromise the integrity of the material by creating tiny holes. Preventing this could save money on repairs and maintenance (Taylor, 1985). Additionally, the expansion of the tube colonies of *Jassa marmorata* could pose as a threat to other native species that cannot compete with the rapid growth of *Jassa marmorata* colonies and are essentially driven out of their habitat niche. Albeit this is not explicitly mentioned in any study, it is reasonable to state the possibility based on the information gathered in the eco-profile.

4.6 Finding the future bottlenecks

4.6.1 Locations

Even though *Jassa marmorata* possesses the qualities and characteristics to be able to invade certain areas of the Arctic Ocean [see chapter 5.1 - 5.4], there hasn't been any reliable report that confirms that this has already happened. However, there has been one confirmed presence of *Jassa marmorata* in the Arctic Ocean. During the 1991 benthic macrofauna study by Kröncke, *Jassa marmorata* had taken up residence in the rinsing water pump system of the research vessel and was thus transported along a vast stretch of Arctic Ocean [see Appendix 5].

Because no reliable reports have been made on the presence of *Jassa marmorata* in the Arctic Ocean, the only option is to theorize possible locations the species could have invaded. These theories are based on the following assumptions (which in turn are based on the information gathered via the eco-profile).

1. If *Jassa marmorata* was able to "lift" along with the German research vessel that was used during the 1991 expedition than it is likely that this has also happened with other ships. Therefore a vector of introduction is set for *Jassa marmorata* into the Arctic Ocean.
2. Based on the tolerance range of *Jassa marmorata*, and its presence in the 1991 research vessel, it can be said that the species is able to survive the habitat conditions of certain areas within the Arctic Ocean.

Therefore it can be theorized that the locations with the highest risk of an invasion by *Jassa marmorata* are the 23 large harbors within the Arctic Ocean [see Appendix 8 and 9]. These areas of high shipping intensity are frequently accessible during the summer months, while some are currently ice free all throughout the year. This number is only expected to increase, thus the window of opportunity for an invasion of *Jassa marmorata* increases as well.

4.6.2 Impacts

The impact *Jassa marmorata* has on the native ecology at the site of invasion is largely uncertain. However, based on the available data and conclusions drawn from the eco-profile, the following statements can be made on the expected impact of *Jassa marmorata*: *Jassa marmorata* is a species known for its rapid population growth, the presence of this species in harbors in the Arctic Ocean could provide a valuable source of food for predators living in, what is generally considered to be, a region of scarce food supply. Additionally, their rapid construction of tube colonies can facilitate the settlement of other species, as they create niches within an area where there is limited habitable space (i.e. harbors). However, with this rapid expansion they could out-compete native species for space and resources, consequently extruding them from their habitat. In conclusion: Based on the available information it is not possible to distinctly determine if the invasion of *Jassa marmorata* will have a positive or negative impact on the native ecology.

5 RESULTS FROM THE ECO-PROFILE ANALYSIS

The results from the previous chapter have shown that it is possible to determine the possible bottlenecks caused by the invasion of *Jassa marmorata* in the Arctic Ocean by using the eco-profile methodology. The eco-profile has had its test-run. Using the method described in paragraph 3.1.1 visualizes what the quality of the data is, and to what extend the theory of how the eco-profile should work matches the practise of how it actually works.

5.1 Rating of the components and data

Recapitulating and rating the relevance of the eco-profile component and the quality of the data resulted in Table 5 from Appendix 11. The values of the rating system are:

Rating system for relevance of the eco-profile components:

-1: Not relevant for determining the invasion potential of an alien species

0: Impartial information for determining the invasion potential of the alien species

1: Relevant for determining the invasion potential of an alien species

Rating system for quality of the data:

-1: The available data required for the component of the eco-profile is incorrect

0: The data required for the component of the eco-profile is missing

1: The available data required for the component of the eco-profile is correct

The results acquired by filling in table 5 from Appendix 11 are imported into Table 6. Via this table it is possible to see; which components of the eco-profile are actually relevant (R), and the quality of the data on each individual component (Q).

Table 6: The eco-profile with incorporated rating system (complete)

Species information	R	Q	Habitat characteristics	R	Q	Invasion	R	Q	Chances and threats	R	Q
Appearances	1	1	Population characteristics	0	1	Primary transport vectors	1	1	Chances	1	0
Life cycle	1	1	Tolerance	1	1	Future invasion pathways	1	1	Threats	1	0
Feeding habits	1	1	Native habitat	-1	1	Invasion history of the Arctic Ocean	1	-1			

Based on the information gathered from Table 6, it can be said that the component of “Native habitat” is not relevant for the determination of the invasion potential of an alien species. This component will therefore not have to be included into the eco-profile in the future. Additionally it can be said that population characteristics, for the species *Jassa marmorata*, is not relevant for its invasion potential. However this component might be an important contributing factor for other alien species, it is therefore recommended to retain the component of “Population characteristic” until further studies have proven otherwise.

The data from Table 6 suggests it is reasonable to say most of the available data on alien species and the Arctic Ocean is of good quality; meaning that the information is reliable and available. However, it was discovered that the information gathered within the “Invasion history of the Arctic Ocean” component (also the only data source explicitly referring to *Jassa marmorata* in the Arctic Ocean) was false. Additionally during the composition of the “Chances” and “Threats” components it was found there is currently not enough information available on the impact of *Jassa marmorata* on other species.

6 CONCLUSION

The first test of the eco-profile methodology indicated that before the methodology can be applied for the continuation of the SBC program, some alterations should be made to improve its effectiveness for determining current- and future bottlenecks associated with an alien species invasion. The initial analysis of the methodology suggested that the inclusion of the “Native habitat” component is not necessary for determining the invasion potential of an alien species. Also, further research is required to determine whether or not the “Population characteristics” component might be relevant to the invasion success of other alien species.

However, by using the current eco-profile methodology it was successfully determined which data sources are reliable, which aren’t, and which data is missing. This suggests the online scientific data should not be used without first verifying the original source of the dataset (e.g. the false occurrences data of *Jassa marmorata* in the Arctic Ocean). It also implies that the eco-profile methodology is an effective tool for determining the quality of online data sources.

Unfortunately the current time and effort put into filling-in the eco-profile is too great for it to be feasible to use for the SBC program (in this case: 2 months). However, due to the work put into developing my own methodology the current notion on the time it takes to finish the eco-profile is not a good frame of reference. The actual time it will take a person to complete the eco-profile will be shorter and might be a more feasible time-frame for the SBC-program.

7 DISCUSSION & RECOMMENDATION

The results from the eco-profile and the eco-profile analysis indicated that there was a substantial amount of data available on *Jassa marmorata* but none on the invasion of *Jassa marmorata* in the Arctic Ocean. Even still, the possible bottlenecks in response to an invasion of *Jassa marmorata* could be determined by applying the eco-profile methodology. The explanation for this is that conclusions from the eco-profile can be drawn in two different ways; the information is either readily available and can be copied as such, or the specific information is not available but the components that make up that information often are. If this is the case, then the user can deduce its conclusions from the component-information that is available in the eco-profile. This is what makes the eco-profile methodology a useful method for determining bottlenecks. Because it discusses the components that dictate the invasion success of an alien species, and allows the user to analyses these components and deduce a prediction on how the alien species' invasion will most likely occur.

A method similar to the eco-profile methodology is the "fact sheet" made by the (Prince William Sound Regional Citizens' Advisory Council, 2004) [see Appendix 10 for full fact-sheet]. They are both essentially passports containing the characteristics of the species. The main difference between the two methods is that the eco-profile contains far more information on the species. The benefit of this is that, more data sources will need to be used. This will result into more dataset being analysed, thus advancing the Sea Basin Checkpoint research goal, which is to determine the usefulness of these datasets to future studies. Therefore using the eco-profile methodology not only facilitates the ability to predict bottlenecks, it also works as a tool to critically analyse datasets on the subject of alien species.

The analysis methodology described in paragraph 3.1.1 was developed as a tool that: analyses if the eco-profile applied during this research was theorized properly, and visualizes the quality of the data sources. As the analysis suggest, the component "native habitats" does not need to be included into the eco-profile. The same could be said for the component "population characteristics" but further research is needed to determine if this is true for all alien species, or just for *Jassa marmorata*. The analysis method further shows that the overall quality of data used is good However, there are still gaps of knowledge on the subject of alien species in the Arctic Ocean but also datasets containing false information. It is therefore recommended to continue to screen the online datasets their quality and usefulness to future studies.

Moreover, the analysis methodology itself requires reevaluation in further research, to verify if the applied rating system is extensive enough to be able to correctly assess the relevance of the components and the quality of the data. The limited time available prevented an extensive evaluation of the applicability of the evaluation method.

Because of the work put into developing my own methodology the current notion on the time it takes to finish the eco-profile is not a good frame of reference (i.e. 2 months). Ideally, a study towards another alien species should be initiated in order to establish the actual time it takes to finish the eco-profile. By doing this it will be possible to decisively determine the practicality of using the eco-profile methodology for the continuation of the Sea Basin Checkpoint program.

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GLOSSARY

Alien invasive species (AIS)	An organism that inhabits a community or ecosystem it has previously never inhabited before and has the ability to out-compete native species for natural resources for a niche position in that area
Bottleneck	Terminology used to summarize the location and impact of an alien species
Eco-profile	Methodology applied for determining the bottlenecks that occur in response to an alien species invasion
Fouling community	An assemblage of plants and animals that grows on hard substrates
Cryptogenic species	A species whose origins are unknown
European Commission Directorate-General for Maritime Affairs and Fisheries (EC)	The Directorate-General for Maritime Affairs and Fisheries (also known in short as DG MARE) is the Commission department responsible for the implementation of the Common Fisheries policy and of the Integrated Maritime Policy.
Sea Basin Checkpoint (SBC) program	Project commissioned be the EC with the aim to determine how current monitoring programmes and data availability meets the needs of public and private users.
IMARES, SINTEF, MARIS	Cooperative partners of Arcadis that are also involved in the SBC program

8 APPENDICES

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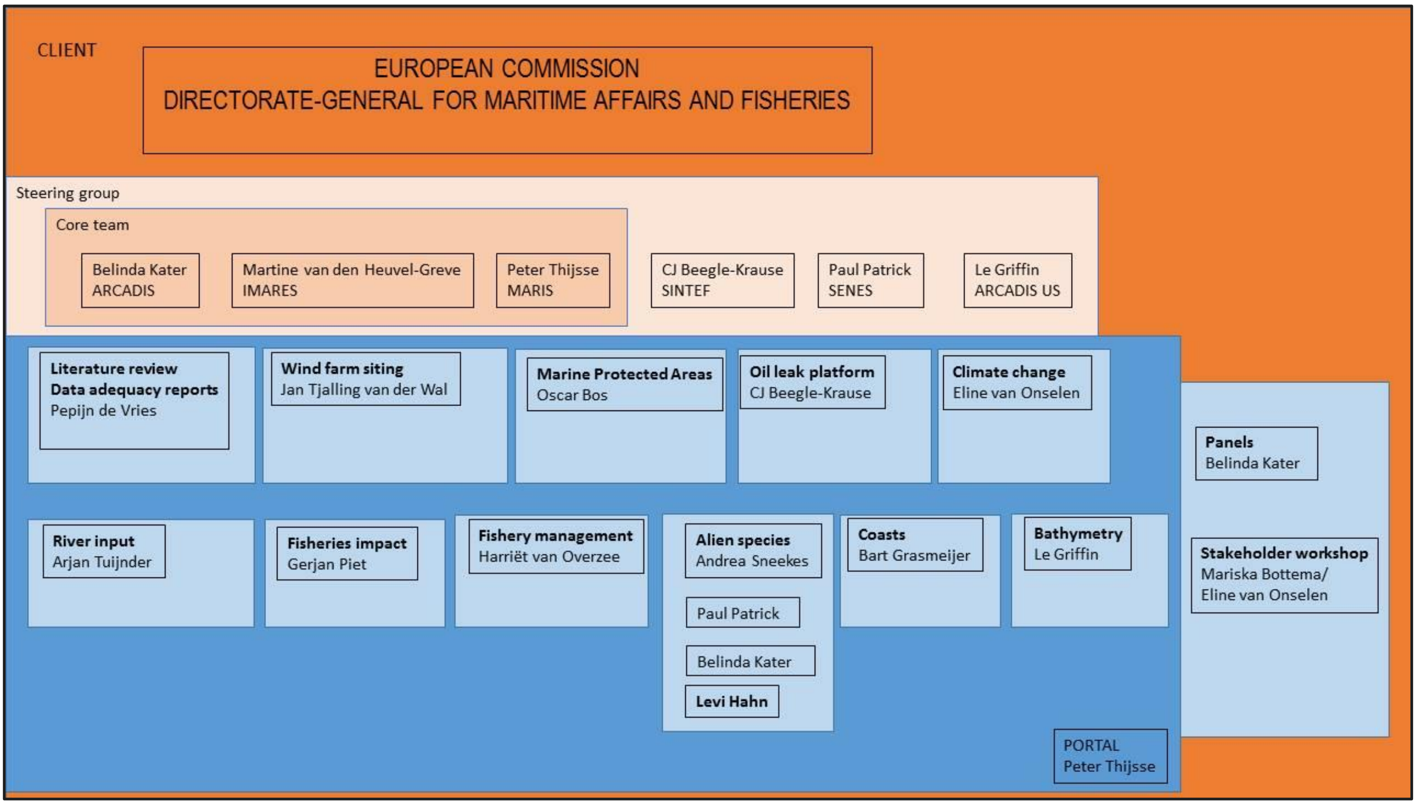
8.1 Appendix 1

Organizational structure of the Sea Basin Checkpoints program with each respected challenge leader



8.2 Appendix 2

Example of a threat scoring system that uses interspecific competition to quantify the magnitude of the impact of an Alien Invasive Species (AIS) (Molnar et al., 2008)

Panel 1. Threat scoring system

Each species in our assessment was assigned a score for each of the following categories (where data allowed), to indicate the magnitude of the threat it poses to native biodiversity. The scoring system was devised so that it could be applied consistently to different types of species and to those living in marine, freshwater, and terrestrial habitats.

Ecological impact

- 4 – Disrupts entire ecosystem processes with wider abiotic influences
- 3 – Disrupts multiple species, some wider ecosystem function, and/or keystone species or species of high conservation value (eg threatened species)
- 2 – Disrupts single species with little or no wider ecosystem impact
- 1 – Little or no disruption
- U – Unknown or not enough information to determine score

Geographic extent

- 4 – Multi-ecoregion
- 3 – Ecoregion
- 2 – Local ecosystem/sub-ecoregion
- 1 – Single site
- U – Unknown or not enough information to determine score

Invasive potential

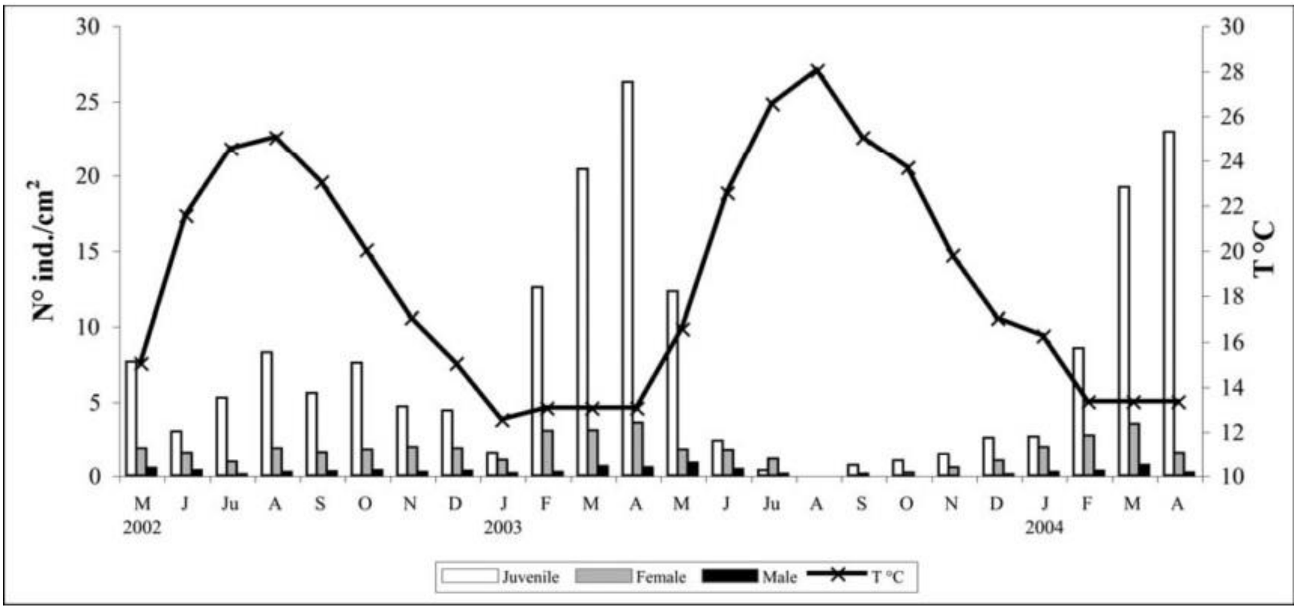
- 4 – Currently/recently spreading rapidly (doubling in < 10 years) and/or high potential for future rapid spread
- 3 – Currently/recently spreading less rapidly and/or potential for future less rapid spread
- 2 – Established/present, but not currently spreading and high potential for future spread
- 1 – Established/present, but not currently spreading and/or low potential for future spread
- U – Unknown or not enough information to determine score

Management difficulty

- 4 – Irreversible and/or cannot be contained or controlled
- 3 – Reversible with difficulty and/or can be controlled with significant ongoing management
- 2 – Reversible with some difficulty and/or can be controlled with periodic management
- 1 – Easily reversible, with no ongoing management necessary (eradication)
- U – Unknown or not enough information to determine score

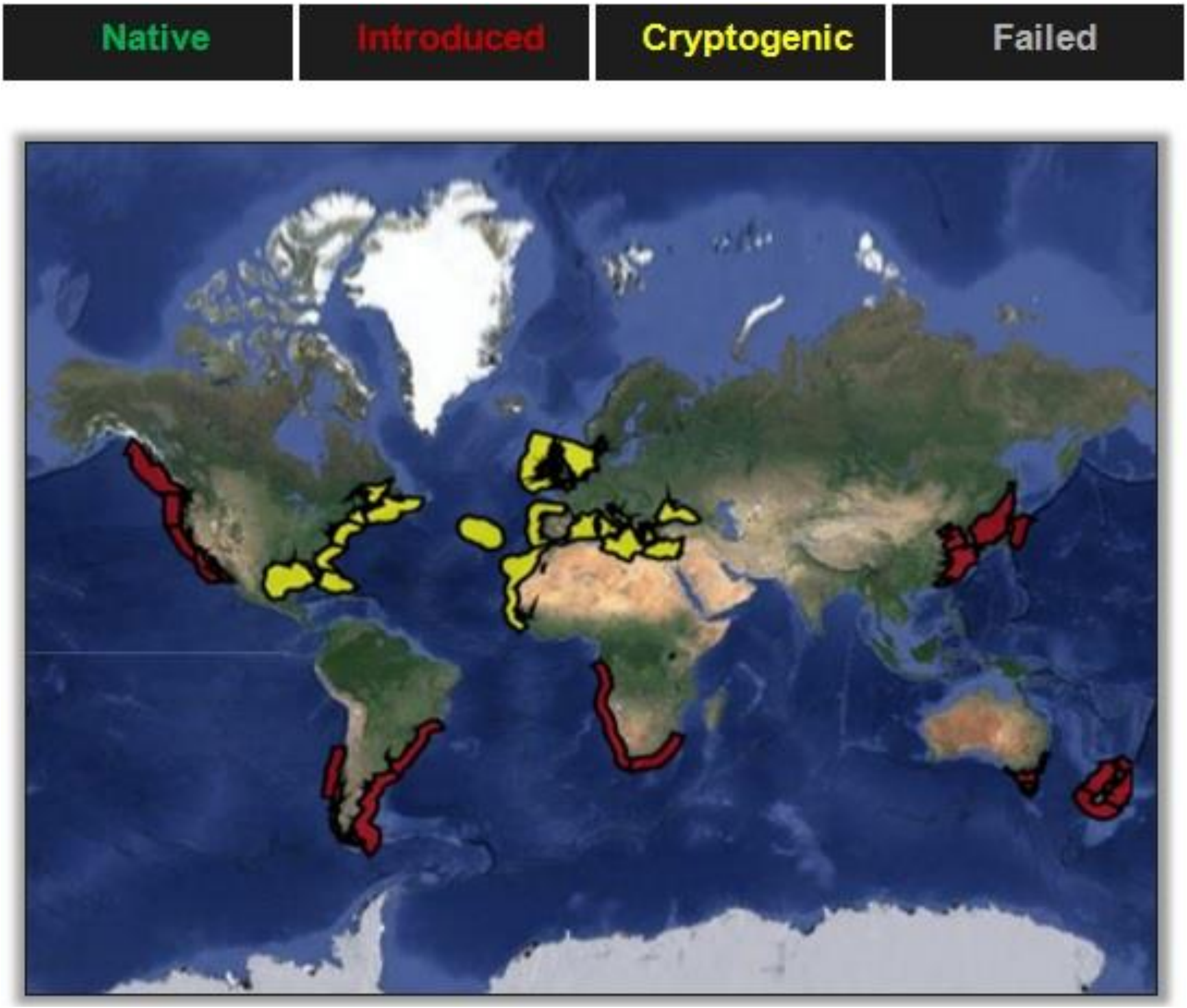
8.3 Appendix 3

Seasonal trend of juveniles, females, and males of *Jassa marmorata*, related to seawater temperature at 5 m depth. The graph clearly shows the increase in juveniles in response to a decrease in water temperature (Mori et al., 2007).



8.4 Appendix 4

Map showing the introduced and cryptogenic habitats of Jassa marmorata. Note that the native habitat of the species is unknown (this is due to historic misidentification as *Jassa falcata*), nor are there any “failed” introductions shown on the map because the species has never purposely been introduced into a new habitat (Fofonoff et al., 2003).



8.5 Appendix 5

A map showing the occurrences of *Jassa marmorata* in the Arctic Ocean (Kröncke, 1994). Note that the location of the occurrences are mostly open ocean, *Jassa marmorata* is not a species that is generally found in such locations, hence the further investigation towards the source of the data. This led to the discovery of the unreliability of the measurements, map from: (GBIF.org, n.d.).

8.6 Appendix 6

Summer sea ice concentration in 1984

This map was downloaded from arkgis.org. Photos, graphics and text on this page must be referenced correctly for further use.

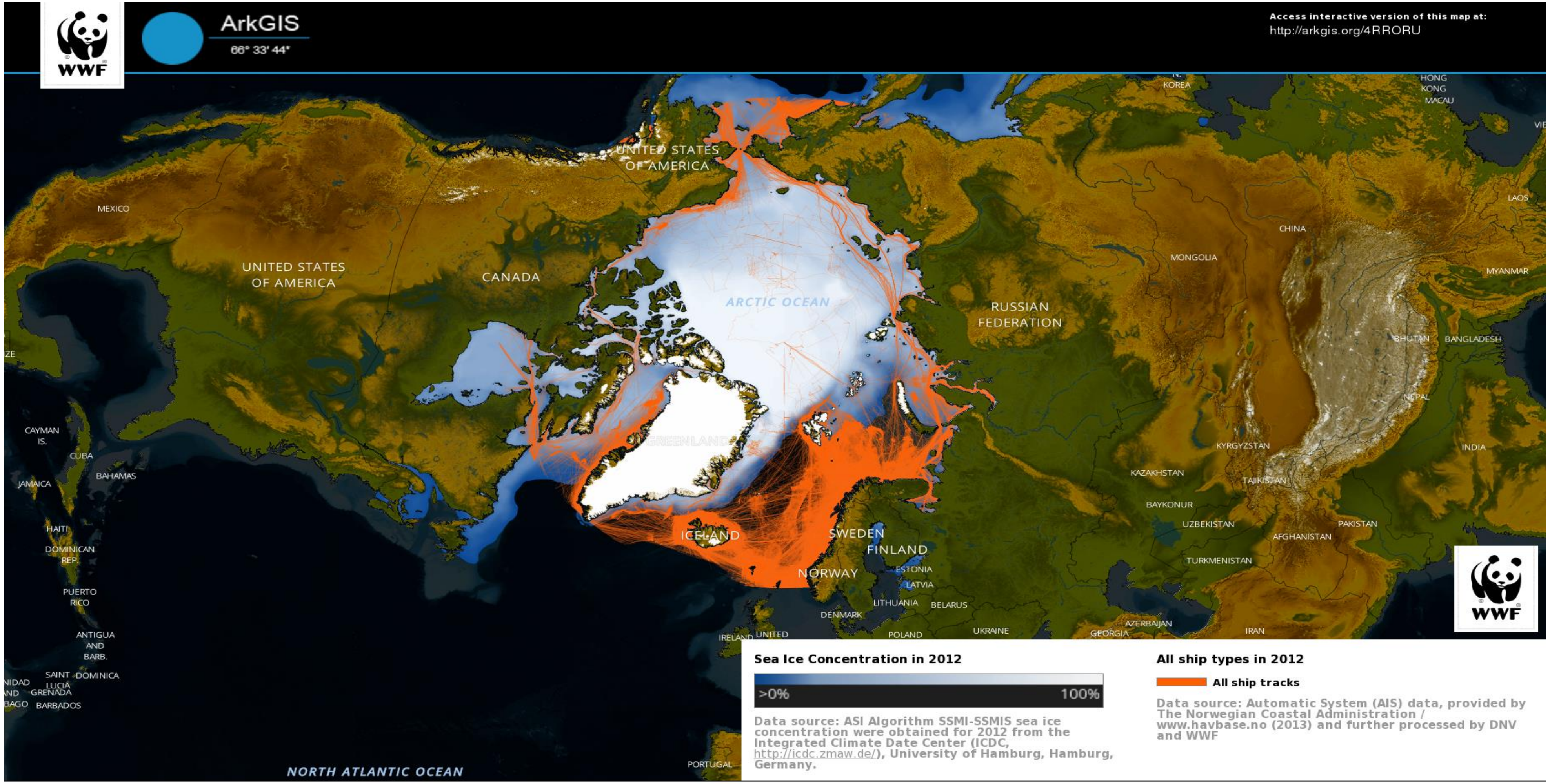
8.7 Appendix 7

Summer sea ice concentration in 2012

This map was downloaded from arkgis.org. Photos, graphics and text on this page must be referenced correctly for further use.

8.8 Appendix 8

All year sea ice concentration and all ship traffic lines in 2012. Note that some ship tracks go through the sea ice; these routes are generally only accessible during the summer months. In winter, the majority of the ships go around the sea ice along the coast.



This map was downloaded from arkgis.org. Photos, graphics and text on this page must be referenced correctly for further use.

8.9 Appendix 9

Ports and harbours of the Arctic Ocean, with a total number of: 23 (Wikipedia, 2016).

Country	Port
Canada	Churchill
Canada	Tuktoyaktuk
Greenland	Nuuk
United States	Prudhoe Bay
United States	Barrow
United States	Kivilina
Iceland	Akureyi
Norway	Hammerfest
Norway	Honnsingvag
Norway	Kikrkenes
Russia	Arkhangelsk
Russia	Belomorsk
Russia	Dikson
Russia	Dudinka
Russia	Kandalashka
Russia	Igarka
Russia	Murmansk
Russia	Naryan-Mar
Russia	Severomorsk
Russia	Tiksi
Russia	Pevek
Russia	Vitino
Total:	**23**

8.10 Appendix 10

The fact sheet on *Jassa marmorata* discusses many of the same components as the eco-profile methodology, but in much less detail (Prince William Sound Regional Citizens' Advisory Council, 2004)

NON-INDIGENOUS AQUATIC SPECIES OF CONCERN FOR ALASKA

Fact Sheet 14 — Tube Dwelling Amphipod

Jassa marmorata

BIOLOGY & PHYSIOLOGY

Physical Description: Adult Tube Dwelling Amphipods ("Amphipod") average 0.24 inches in length and range from 0.12-0.35 inches. Amphipods have large rounded eyes that are located entirely or partially within the lateral lobe of the head and two large antennas that are approximately one-half the body length or greater. They are typically greyish in color with distinct brown markings. Amphipods exhibit morphological dimorphism, which means that its size is a function of the water temperature. Higher water temperatures produce smaller Amphipods. Also, female Amphipods are generally more fertile in colder water. Males do not live as long as females but attain greater size by growing faster through fewer molts. Males come in two forms: "major" and "minor." Majors are about twice as big as minors and females and have an enlarged "thumb." The thumb develops only after the last molt.

Photo by: Marine Biological Laboratory Woods Hole Massachusetts

Nutrition Requirements: Amphipods inhabit self-constructed tubes from which they extend the anterior half of their bodies to gather plankton, detritus and other materials by filter feeding. They also engage in intraguild predation (the killing and eating of a species that are potential competitors) and cannibalism as feeding strategies. In Amphipods, the proportion of major to minor males is determined by the amount of protein rich food sources in the surrounding habit. Some studies have shown that major males are predominant during the months of June and July, especially if a phytoplankton bloom occurs during the previous spring months. Protein and fatty acid rich diatoms are a major component of the plankton community.

Reproduction: Amphipod males exhibit dimorphic reproductive behaviors (fighting vs. sneaking strategies). Minor males are morphologically more similar to females and thus are able to avoid attacks by major males. On the other hand, major males normally engage in combat with other major males while guarding females. The onset of sexual activity in major males is signaled by the development of the thumb. Field observations have shown that fighting males remain perched upon the tube that females inhabit and wrestle other major males away from the female, whereas minor males slip under their surveillance and engage in sneak matings. The second gnathopod is the prime appendage of use in agonistic encounters, but the thumb is not used as a weapon or a physical means to dislodge the opponent. The thumb may minimize aggressive encounters by signaling dominance and provide access to females. Females accept the proximity of thumbed males more than they do thumbless males. On the other hand, during later molts, minor males are as capable as major males of successfully fertilizing females. The mating system in Jassa in polygynous and both sexes mate multiple times during their lifetimes, but females must mate within 1-2 hours after molting. Females engage in sole parental care.

Lifecycle Stages: In Amphipods, mating occurs after the female molts. The embryos are brooded in a maternal pouch and the offspring hatch and crawl away to build a tube not far from their parents. Females spend their time within their tubes feeding, mating, and tending their young. Several broods of offspring are produced, each potentially fertilized by a different male. Males spend most of their time within their tubes as juveniles, but at the last molt a marked change in morphology and behavior occurs. Strong competition among males for mates is promoted by many of the life-history characteristics of this species including: (1) a sedentary, colonial existence, (2) a polygynous mating system, (3) reproduction by the female that is continuous but not at a consistent phase or

Prince William Sound Regional Citizens' Advisory Council — *Updated: 7/6/04* rate (asynchoronous), (4) a brief ovulatory period, (5) lack of sperm storage, and (6) sole parental care by the female.

Habitat: The Amphipod lives within fouling communities such as docks and pilings. It builds tubes among algae, sponges, tunicates, and is found on mid to high-latitude rocky shores in both the southern and northern hemispheres. Amphipods are native to the northwest Atlantic.

DISPERSAL POTENTIAL

Historical and Current Introduction/Spread: The Amphipod is globally distributed. It was first discovered in California in 1941, first recorded in the San Francisco Bay in 1977, and first recorded in Puget Sound in 1990. Its original distribution includes the North Atlantic Ocean and the Mediterranean Sea. Amphipods were first discovered in Prince William Sound in 1999 and have been documented in the University of Alaska collections; however, the magnitude and extent of invasion into Alaskan waters is not well understood at this time.

Dispersal Methods: Amphipods move by crawling and sometimes by swimming, rarely leaving the tube in which they inhabit. Amphipod juveniles, especially the smallest individuals of less than 0.06 inches in length, are responsible for this species' short distance dispersal. Once inoculated into an area, the Amphipod does not tend to disperse very widely, and tends to remain a local invasive species issue at the point of inoculation. In one study conducted, Amphipods captured and released approximately 3 feet from a floating dock, swam directly back to the same dock, regardless of location of release. Possible vectors for the long distance dispersal, and inoculation of the Amphipod is through transportation in ballast water or on the bottom of a ship's hull.

IMPACTS AND CONTROL

General Impacts: The Amphipod can compete with native marine organisms for food and space. Studies have also shown that Amphipods may play important roles in determining the type and distribution of algal communities, particularly where predation pressure is low.

Management Information: Currently, there is little information on the control and management of Amphipods, once established in a new habitat. However, since Amphipods have been collected in ballast water samples, ballast water treatment may prove successful in limiting the distribution into new habitats.

Key Notes: *Jassa herdmani* and *Jassa falcata* are easily confused, morphologically, with the Amphipod.

Prince William Sound Regional Citizens' Advisory Council *Updated: 7/6/04*

8.11 Appendix 11

Rating system [Table 5] on the relevance of the eco-profile components to the invasion potential of an alien species, and the analysis of the quality of the used data:

Table 5: Rating system for determining the relevance of the components of the eco-profile, and the quality of the available data used during the research (Complete)

	Recapitulation of content	Relevance score	Quality score
Appearances	Size can be a determining factor	1	1
Life cycle	Influence temperature on reproduction	1	1
Feeding habits	Formation of extensive colonies & food source	1	1
Population characteristics	Fouling communities can thwart human activities	0	1
Tolerance	A high tolerance increases the invasion potential	1	1
Native habitats	Native habitat unknown	-1	0
Primary transport vectors	Shipp hull fouling and ballast water main transport vectors	1	1
Future invasion pathways	Disappearance of sea ice will lead to an increase in shipping activity	1	1
Invasion history of the Arctic Ocean	Currently no confirmed invasion of the Arctic Ocean by *Jassa marmorata*	1	-1
Chances	Native species could feed of off *Jassa marmorata*	1	0
Threats	Expansion of the tube colonies of *Jassa marmorata* could pose as a threat to other native species	1	0