6. Invasive Species: Case studies from Iceland

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6.1 Introduction

In the last decades the transport of species to areas outside their natural distribution range has increased enormously, globally. It has been estimated that some 10,000 species are being transported every day throughout the globe and in European coastal waters alone non-native species are discovered on the average every second or third week (Bax *et al*. 2003, Streftaris *et al*. 2005). The main pathways of transport are considered to be by humans such as hull fouling of ships, ballast water, transport of aquaculture animals, especially shellfish, and with international aquarium trade (Stachowicz *et al*. 2002, Padilla and Williams 2004).

By far the biggest group of introduced marine species are benthic organisms, phytobenthos and zoobenthos (Streftaris *et al*. 2005). Larvae, spores and young stages of benthic species are most likely transported by ballast water while adult stages have a better chance as fouling on ship hulls or associated with mollusc shells that are being transported long-distance. Molluscs and fish have been transfered for aquaculture purposes for centuries and it is still a common practice worldwide. Aquaculture species may transfer diseases (viruses and bacteria) and parasites, and hitch hiking species that can survive in the new environment and potentially cause threat to the native biota (Brenner *et al*. 2014).

Inter-ocean transport of non-native species has also been facilitated by global warming which has caused reduced Arctic ice cover during summer and aided drift of pelagic species from the North Pacific through the North-western Passage into the North-west Atlantic (Reid *et al*. 2007, Corbyn 2007). Man-made canals as the Suez Canal have also opened routes for the transport of organisms between oceans (Galil 2009).

Only a small fraction of the numerous species that are transported over long distances each day survives the transport, and still fewer withstand the environmental conditions at the site where they are released (Crooks and Soulé 1999, Mack *et al*. 2000).

There are many examples of introduced species that are more successful in their new destination than in the area they originate from. This has in some instances been thought to be caused by the lack of natural enemies in the new habitat (Stæhr *et al*. 2000).

It may take many years, even decades before the impact of introduced species can be detected (Crooks and Soulé 1999). Of those introduced species that successfully colonize, some become invasive, i.e. affect the recipient habitat and bioregions, economically, and/or ecologically even though the seriousness of the impact can vary greatly. Changed environmental conditions (as e.g. increased sea temperature in the North-Atlantic) may affect the success of a non-indigenous species in the new environment (Occhipinti-Ambrogi 2007, Sorte *et al*. 2010).

The impacts of introduced species can be either direct e.g. when they alter trophic interactions, interfere with competition (for food and space) and by disease transmission or indirect through habitat modification (Snyder and Evans, 2006, Wallentinus and Nyberg 2007). The consequences are changes in species diversity of the native biota (Eastwood *et al*. 2007, Williams and Smith 2007, Hollebone and Hay 2008, Weis 2010) and in some instances displacement of native species (McDonald *et al*. 2001). Hybridisation has also been indicated as a consequence of introduction of new species but has scarcely been studied (Coyer *et al*. 2007).

The highest number of registered invasions of non-native marine species, is in Europe. These species belong to almost all groups of marine organisms from bacteria to fish (Streftaris *et al*. 2005), and the majority originates from the Pacific (Molnar *et al*. 2008).

Although the number of non-native species is relatively well known in Europe little is known of their effect on local biota. Studies indicate that invasive non-native species can cause changes in the recipient biota and are considered to be the greatest threat to biodiversity and ecology of marine communities in European coastal waters (Bax *et al*. 2003). Because of that, there is an identified need by the scientific community for a risk-based assessment of the transport and introduction of non-native species. Risk assessments should include all possible effects of the introduction both direct effects and side effects such as diseases, hitch hiking species and genetic contamination (Muehlbauer *et al*. 2014).

Human induced introductions of non-native species in Icelandic waters have increased in the last decades. Most of these species originate from the Pacific and are brought to Iceland from Europe as a secondary introduction (Table 1). Only minor negative effects on the ecosystem have been reported for these species in Iceland. However, it is emphasised that there have been limited ecological studies of their interaction with native species.

Table 1: Non-native marine species in Icelandic waters

Taxa	First recorded	Pathway	Invasive	References
Phytoplankton				
Heterosigma akashiwo	1987, Southwest	Shipping	No	Thorarinsdottir and Thordardottir 1997
Stephanopyxis turris	1997 Southwest	Shipping	No	Gunnarsson *et al*. 2011
Mediopyxis helysia	2007, West	Shipping	No	Gunnarsson et al. 2011
Neodenticula seminae	2002, North	Currents	No	Reid *et al*. 2007
Macroalgae				
Fucus serratus	1900, Southwest	Shipping	Potentially	Jónsson 1903
Codium fragile	1974, Southwest	Shipping	No	Jónsson and Gunnarsson 1975
Bonnemaisonia hamifera	1978, Northwest	Shipping	No	Gunnarsson and Egilsdóttir 2010
Crustacea				
Cancer irroratus	2006, Southwest	Shipping	Potentially	Gislason *et al*. 2014
Crangon crangon	2003, Southwest	Shipping/ currents	Potentially	Gunnarsson *et al*. 2007
Mollusc				
Mya arenaria	1958, Southeast	Shipping	No	Óskarsson 1982
Cerastoderma edule	1948, Southwest	Shipping	No	Óskarsson 1982
Tunicata				
Ciona intestinalis	2007, Southwest	Shipping	No	Svavarsson and Dungal 2008
Fish				
Platichtys flesus	1999, Southwest	Shipping/ currents	Potentially	Jónsson *et al*. 2001
Oncorhynchus mykiss	1983, Southwest	Acuaculture	No	Jónsson 1983

In this article we describe the present status of non-native marine species in Icelandic waters. We attempt to identify their distribution in Iceland and the vectors for spread, and how the introduced species interact with the local biota.

6.2 Phytoplankton

6.2.1 Heterosigma akashiwo (Y. Hada) Y. Hada ex Y. Hara & M. Chihara

A blooming of the planktonic algae *Heterosigma akashiwo* (Figure 1) in Hvalfjörður was observed in May 1987 causing massive mortality in pen reared salmon at a local fish farm (Thorarinsdottir and Thordardottir 1997). The species has only been found in Iceland on this one occasion. This could possibly be explained by a single introduction event during optimal environmental conditions, as the species did not survive the conditions for the rest of the year and died out.

Figure 1: Heterosigma akashiwo

Photo: Wenche Eikrem and Jahn Throndsen.

H. akashiwo was first formally described form Japan in 1967 (see Hara and Chihara 1987). In Europe it was first reported from a dens bloom in Oslofjord in 1964 (Braarud 1969). Since then it has been reported in many places in the North Atlantic where it has caused several incidents of mortality in farmed fish and shellfish. Due to the close genetic relationship that exists between Pacific and Atlantic populations *H. akashiwo* has been thought to have been introduced recently into the Atlantic, possibly by humans (Connell 2000). But given the global distribution of this species this has been challenged (Smayda 2006).

6.2.2 Stephanopyxis turris (Greville et Arnott) Ralfs

The diatom *Stephanopyxis turris* (Figure 2) was first recorded in 1997 when it was found in Hvalfjörður (Eydal 2003, Gunnarsson *et al*. 2011). It has since been found in Faxaflói and Breiðifjörður. *S. turris* is a common species at the Atlantic coast of Europe and the east coast of North America. The species had not been found in numerous surveys in the area until it suddenly appeared and was found in high concentrations in Hvalfjörður. It is therefore suspected that it was introduced a shortly before it was first recorded.

Figure 2: Stephanopyxis turris

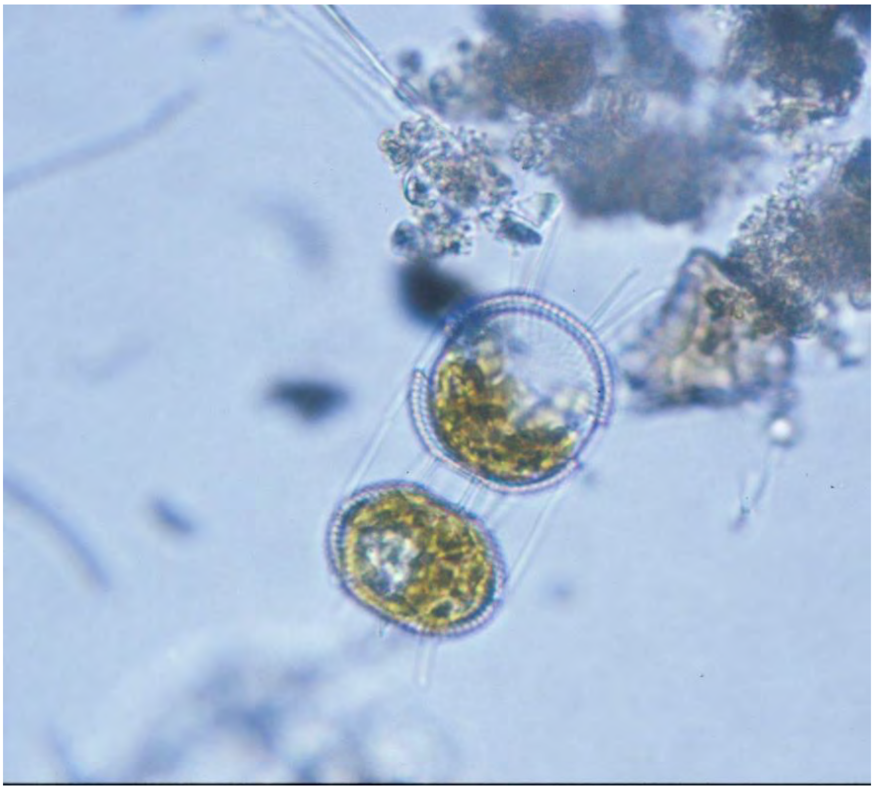

Photo: Karl Gunnarsson.

6.2.3 *Mediopyxis helysia Kühn, Hargraves et Hallinger*

The first formal description of the diatom species *Mediopyxis helysia* (Figure 3) was published in 2006 (Kühn *et al*. 2006). It was first found in samples collected on the west coast of North America in 1996. Subsequently it was found close to Helgoland in the North-Sea coast in 2002, and at the Scottish coast in 2005 (McCollin 2008). It is not known from where it originates but detailed examinations of samples from the west coast of N-America and Helgoland in the years prior to its discovery did not reveal any individuals of this relatively large and conspicuous species (Martin and LeGresley 2008, Kraberg *et al*. 2012).

In 2007 through 2010 the species was found at numerous occasions in Breiðafjörður western Iceland (Gunnarsson *et al*. 2011) and in Hvalfjörður in 2010. Recently it was found in samples collected in 2008 in Tálknafjörður, north-western Iceland (H. Gudfinnson MRI, personal communication). Re-examining of samples from Breiðafjöður and Hvalfjörður taken before its discovery in 2007 did not yield any additional records of the species.

Figure 3: Mediopyxis helysia

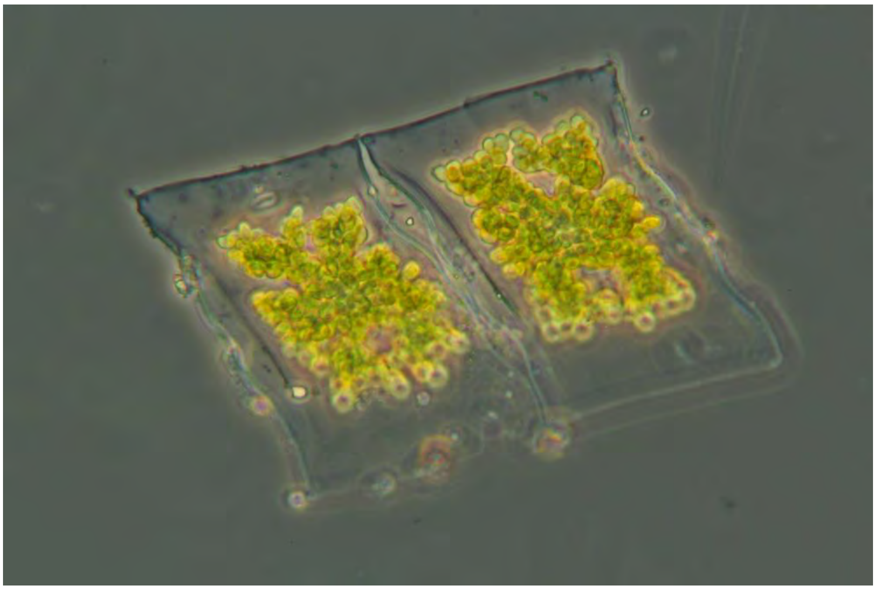

Photo: Karl Gunnarsson.

In the Wadden Sea the species has become established and has repeatedly formed extended blooms (Meier and Hillebrand 2012). Its dominance in the plankton community has affected the diversity of the phytoplankton and consequently it has been considered to be an invasive species.

6.2.4 *Neodenticula seminae (Simonsen et Kanaya) Akiba et Yanagisawa*

Neodenticula seminae (Figure 4) was discovered in Icelandic waters in samples collected by continuous plankton recorders (CPR) in 2003 and in samples taken in the North Icelandic waters in 2002 (Reid *et al*. 2007). The species was first detected in the North Atlantic in 1999 in the CPR series south of Greenland. Recently it was found to be abundant in the Nordic Seas up to Svalbard (Miettinen *et al*. 2013). It has probably drifted with currents from the Pacific along the Northwest Passage as a result of longer ice-free periods in summer in the Canadian Arctic (Corbyn 2007).

Figure 4: Neodenticula seminae

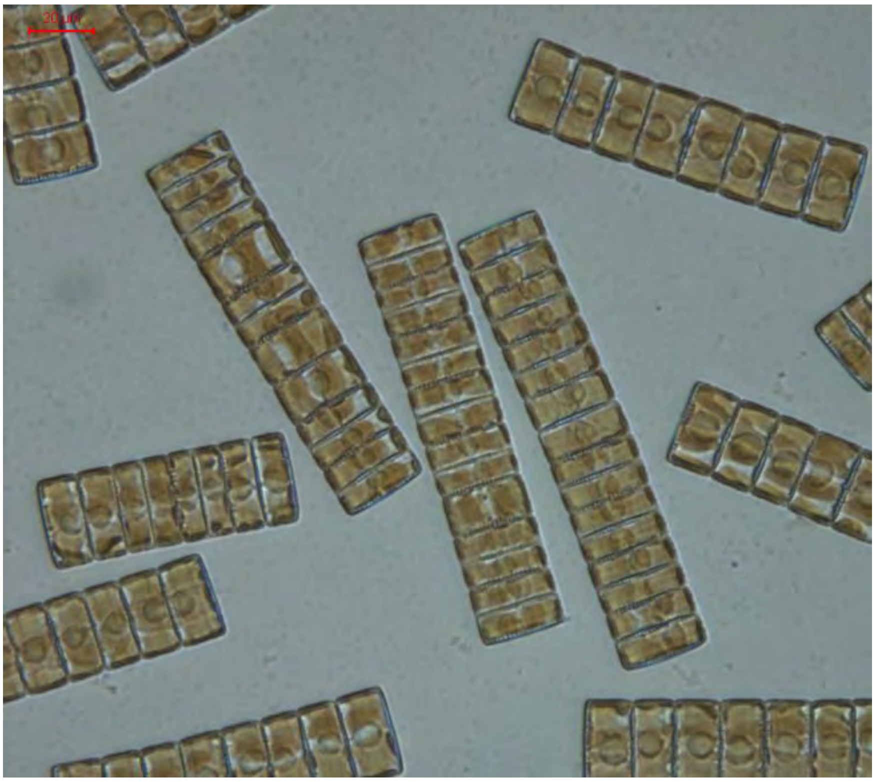

Photo: Akira Kuwata.

N. seminae has until now only been found in two samples from Icelandic waters. One of the samples was taken off the south coast and the other one on the northern shelf. It was not introduced by humans but its introduction was facilitated by global warming and resulting ice melting in the Arctic.

6.3 Macroalgae

6.3.1 Fucus serratus Linneaus

The brown seaweed *F. serratus* (Figure 5), native to the Atlantic coast of Europe, was probably introduced to Iceland by man. It was first recorded at the end of the 19th century in two isolated populations in south-western Iceland (Jónsson 1903). In recent years the population has extended its distribution over most of the western and northern shore of Reykjanes peninsula, south-western Iceland. Additionally, small isolated population was found in Hvalfjörður in 1998 which now covers most of the shores in the inner and middle part of the fjord. Molecular genetic analyses indicate that *F. serratus* was introduced to Iceland a few centuries ago and has since spread from Iceland to the Faroe Islands (Coyer *et al*. 2006).

Figure 5: Fucus serratus

Photo: Karl Gunnarsson.

Hybridisation is commonly found between *F. serratus* and *F. distichus* especially in areas where the species have recently started growing together i.e. when one is introduced into the habitat of the other. In Iceland hybrids are commonly found between the two species (Coyer *et al*. 2006). These hybrids seem to be most common at the edges of the spreading area of *F. serratus* where the two species are in direct contact.

In old established populations, *F. serratus* is considered a week competitor with other canopy forming species (Hawkins and Harkin 1985). Studies in Iceland have however shown that the growth of *F. serratus* affects or eliminates the growth of other canopy-forming species normally found growing at the same level in the lower part of the shore (Gunnarsson and Galan 1990, Ingólfsson 2008). When established, *F. serratus* becomes dominant by forming a canopy cover in the lower part of the shore, reducing or eliminating the cover of other canopy forming algae. It can therefore be classified as an invasive species.

6.3.2 Bonnemaisonia hamifera Hariot

The Japanese red seaweed *Bonnemaisonia hamifera* (Figure 6) was first recorded in the North Atlantic at the end of the 19th century. It spread from Europe to the west coast of North America where it was recorded in 1927. First record of it in Iceland was sometimes between 1964 and 1975 (Munda 1978). The species normally has a life cycle with morphologically dissimilar phases. Its sporophytic phase is made of thin filaments, growing closely attached to the substrate or forming small tufts. The gametophytic phase is a larger, upright fleshy plant. *B. hamifera* i.e. the sporophytic phase was first reported growing on *Fucus distichus* in the intertidal zone in Dýrafjörður. The species was recorded again in 2004, when it was found subtidally in Hvalfjörður, again it was only the sporophytic phase that was found and it was growing attached to the calcareous algae *Lithothamnion* (Gunnarsson and Egilsdóttir 2010). It formed small, pink tufts on the host. The gametophytic phase has not been reported in Iceland.

Figure 6: Bonnemaisonia hamifera

Photo: Svanhildur Egilsdóttir.

In Europe and the west coast of North America reproductive structures have been observed both on gametophytic and sporophytic plants (Floc'h 1969, Chen *et al*. 1969). The species is however thought to spread primarily by fragmentation. No reproductive structures have been found on the species in Iceland. Sporophytes have a wider distribution in the North Atlantic than the gametophytes and are the only life cycle stages found close to its northern distribution limit. Here it seems to spread exclusively by fragmentation. Experiments have though shown that the sporophytes are able to form spores when the sea temperature is above 10 °C during short day conditions (d<12 hrs). It occasionally happens in Iceland that the temperature is above 10°C after the autumn equinox but does probably not last long enough for the spores to mature and germinate to form viable gametophytes.

Bonnemaisonia hamifera is has been found to be invasive in other areas, but in Iceland it is rare inconspicuous and cannot be termed invasive.

6.3.3 Codium fragile (Suringar) Hariot

The green seaweed *Codium fragile* (Figure 7) was first recorded in Iceland in 1974 when it was found in Hvalfjörður, southwestern Iceland (Jónsson and Gunnarsson 1975). It has now also been recorded on the western and northern coast of the Reykjanes peninsula (Gunnarsson and Egilsdóttir 2010). The plants grow up in spring from filamentous masses left at the holdfast from previous summer. The macroscopic plants disappear again in late autumn. No reproductive structures have been found on the Icelandic plants.

6.4 Figure 7: Codium fragile

Photo: Karl Gunnarsson.

Codium fragile is a very morphologically variable species and numerous subspecies have been described that can be difficult to distinguish. In the North Atlantic three subspecies have been described; subspecies *tomentosoides*, *atlanticum* and *scandinavicum.* It was thought that the different subspecies were introduced from the Pacific in three separate events (Silva 1955, 1957). Later studies have indicated that there are actually only two subspecies in the North Atlantic; subspecies *fragile* and subspecies *atlanticum*. The subspecies *fragile* is now the only one considered to have been introduced from the Pacific to the North Atlantic, subspecies *atlanticum* is considered to be native (Brodie *et al*. 2007, Provan *et al*. 2008). In Iceland *C. fragile* is found in rock pools in the upper littoral and just below low watermark at spring tide. The biggest specimens are 15 cm.

In Europe and the east coast of North America the species has become very common and dominates the vegetation in places (Scheibling and Gagnon 2006). Sometimes causing nuisance e.g. by dislodging commercial shellfish and clogging dragnets (Fralick & Matthieson 1973, Carlton and Scanlon, 1985) and therefore defined as an invasive species. In Iceland, however, *Codium fragile* is nowhere common although it has been present for at least 40 years and does not show any invasive characteristics here.

Studies have shown that for reproduction to occur in *C. fragile* the sea temperature needs to reach at least 12 °C (Churchill and Moeller 1972). In Iceland the temperature often exceeds this limit during late summer in the inner parts of fjords in the southwest and west part of the country (Jónsson 1999). Therefore *C. fragile* might occasionally be able to reproduce in Iceland or at least start developing reproductive structures.

6.5 Crustaceans

6.5.1 Cancer irroratus Say, 1817

The Atlantic rock crab *Cancer irroratus* was first recorded in Icelandic waters in 2006 (Gíslason *et al*. 2014). This was as well the first record of the species colonization out of its native range, the Atlantic coast of N-America (Williams 1984). This relatively large decapod crab (Figure 8), with carapace width up to 15 cm, is considered to have been introduced to Iceland as larvae via ballast water (Gíslason *et al*. 2014). The large scale changes in the North Atlantic in recent years (Anonymous 2004), with noticeable warming in Icelandic waters (Astthorsson *et al*. 2012) are likely to have aided the colonization. Since colonization *C. irroratus* has spread quickly along the southwest and west coast of Iceland, and has now colonized approximately 20% of the coastline. In its new habitat competing decapods are scarce, with only two commonly found, the European green crab (*Carcinus maenas*) and the great spider crab (*Hyas araneus*). Despite of its recent colonization *C. irroratus* appears to be the dominant brachyuran crab species in south-western Iceland, both regarding adults and planktonic larvae (Gíslason *et al*. 2014). The density of adult *C. irroratus* was estimated to be around 0.12 crabs per square meter (Gíslason *et al*. 2013a) which is similar to observations in its native range (Miller 1989). Studies on the genetic population structure revealed that the genetic variation in the Icelandic population is high and similar to what it is in its native range (Gíslason *et al*. 2013b, Gíslason *et al*. 2013c). Nothing is yet known about the predator-prey interaction and effects of *C. irroratus* on marine ecosystems in Iceland. Considering the size and generalist diet *C. irroratus* is capable of having significant effects on a variety of native benthic organisms, e.g. through direct predation, competition for habitat or indirect trophic cascades (Gíslason *et al*. 2014).

Figure 8: Cancer irroratus

Photo: Ó. Sindri Gíslason.

The size and abundance of adult crabs, their reproductive condition, occurrence of all larval stages in plankton, high genetic diversity, apparent lack of founder effects and rapid spreading of the species along the coastline indicate that the newly established *C. irroratus* population is healthy and is thriving well in Icelandic waters. Thus according to current knowledge, *C. irroratus* has the potential to become invasive in Icelandic waters.

6.5.2 *Crangon crangon (Linnaeus, 1758)*

The European brown shrimp (*Crangon crangon*) (Figure 9) was first recorded in Icelandic waters in 2003 (Gunnarsson *et al*. 2007). In light of its occurrence in Arctic waters, and with records of its incidental observations in Icelandic waters dated back to the late 19th century (Campos and van der Veer 2008, Doflein 1900), it is interesting that successful colonization has not occurred before. The species native distribution extends from the White Sea and northern Norway, the Baltic in the north to the Atlantic coast of Morocco, including the Mediterranean and the Black Sea in the south (Campos and van der Veer 2008, Tiews 1970) where the shrimp inhabits eulittoral and sublittoral soft-bottom habitats of temperate waters, commonly in large numbers (Henderson and Holmes 1987, Hostens 2000). Since colonization *C. crangon* has spread quickly along the south and west coast of Iceland, and has as well isolated population in the southeast Iceland (Gunnarsson *et al*. 2007, Kolbenstein 2013). Introduction of *C. crangon* in Icelandic waters is either thought to have occurred naturally via larval drift by currents or by multiple introductions via ballast water, or even both. Known ecological impacts of its colonization in Iceland has not been estimated, the density of *C. crangon* has however been measured as high as 6,700 animals per 100 m^2 (Gunnarsson *et al*. 2007). In general *C. crangon* is a carnivorous nocturnal predator with diet determined by the composition of the benthic community and the abundance of available prey, both of which are strongly correlated with substrate type (Ansell *et al*. 1999). As *C. crangon* has also been implicated as a major predator of young plaice (*Pleureonectes platessa* L.) on nursery grounds (Oh *et al*. 2001, van der Veer *et al*. 1998, Wennhage 2002) its possible impact in Iceland is of special concern as the plaice is a commercially valuable species.

Figure 9: Crangon crangon

Photo: Hans Hillewaert.

6.6 Molluscs

6.6.1 Mya arenaria Linnaeus, 1758

Mya arenaria, the Sand gaper, (Figure 10) is found in all European seas and is widely distributed along European coasts (Poppe and Goto 1993, Strasser 1999). This is the oldest introduced species documented in European waters, as shells found in Denmark have been dated back to 1245–1295 (Petersen *et al*. 1992). This species was first observed off the east coast of Iceland in 1958 (Óskarsson 1982). Since then it has been found at several places almost all around Iceland but always in low abundance (Thorarinsdottir *et al*. 2007). The transport of *M. arenaria* to Iceland is most probably from Europe by natural currents and/or ballast water. It is difficult to identify impacts of *M. arenaria* in Icelandic waters, but in the Baltic (Obolewski and Piesik 2005) and in Danish fjords (Christiansen *et al*. 2006, Petersen *et al*. 2008) this species has invaded and caused regime shift in the last decades.

Figure 10: Mya arenaria

Photo: Gudrun G. Thorarinsdottir.

6.7 Cerastoderma edule (Linnaeus, 1758)

The Common cocle, *Cerastoderma edule*, is widely distributed in the Northeast Atlantic Poppe and Goto 1993) and was first observed in south-western Iceland in 1948 (Óskarsson 1982). The distribution has increased since then but is restricted to the west coast most probably related to sea temperature (Figure 11). The transport to Iceland is most probably from Europe by natural currents and/or ballast water. The impact is hard to detect as it is always found in very low abundance, but the species might compete for resources such as food and space with other bivalve species in the same locality as *Arctica islandica* and *Serripes groenlandicum*.

Figure 11: Cerastoderma edule

Photo: Gudrun G. Thorarinsdottir.

6.8 Tunicata

6.8.1 Ciona intestinalis (Linnaeus, 1767)

Tunicates commonly foul ships and docks and are transported around the globe with ships. The Sea vase tunicate*, Ciona intestinalis,* (Figure 12) is the only tunicate species that has been recorded as non-native in Icelandic waters. This species, is globally distributed except in Antarctica and is native to the North Atlantic, but is introduced to the South Atlantic, Pacific, and Indian Oceans (Dybern 1967). *C. intestinalis* is listed as an invasive species in Canada (Therriault and Herborg 2008, Carman *et al*. 2010) and South Africa (Robinson *et al*. 2005) having negative economic impacts on shellfish aquaculture, reducing growth rates of cultured mussels and fouling ropes and equipment. It is also a formidable competitor, quickly occupying space and potentially displacing native fouling species.

Figure 12: Ciona intestinalis

Photo: Pálmi Dungal.

In Iceland *C. intestinalis* was first recorded in 2007 in a harbour in Straumsvík, south-western Iceland (Svavarsson and Dungal 2008) and again in 2010 from floating docks in three small harbours also in the Southwest (Björnsson 2011). The tunicate has most probably been transported to Iceland as fouling organism on ship hulls. The impact of *C. intestinalis* in Iceland is impossible to detect yet, as it has just lately been recorded at few sites and in low abundance. This species is potentially invasive causing problems in bivalve aquaculture where it has been introduced (Hayes *et al*. 2005, Lambert and Lambert 2003) so further investigations are needed.

6.9 Fish

6.9.1 Platichthys flesus (Linnaeus, 1758)

The European flounder, *Platichthys flesus, (*Figure 13) is widely distributed in the Northeast Atlantic and common in coastal waters in Western Europe as in the Faeroes (Muus *et al*. 1997, Joensen and Taaning 1970). In autumn 1999 *P. flesus* was first observed near the mouth of the Ölfusá river, on the south west coast of Iceland (Jónsson *et al*. 2001, Gudbrandsson and Jónsson 2004). Since then the distribution of the species has increased greatly and it can now be found clockwise around Iceland from the east to the north, in brackish water (Jónsson *et al*. 2001). The introduction pathway for *P. flesus* is unknown, it is considered to be either by natural dispersal with currents from the Faroese or human mediated with ballast water. Records of such human mediated transport are known from the United States for *P. flesus*, though not resulting in successful colonization (Welcomme 1988). Studies on the flounder in Iceland have shown predation on salmon larvae as well as competition for food with salmon, eel and stickleback (Jóhannsson and Jónsson 2007). The species is considered as potentially invasive.

Figure 13: Platichthys flesus

Photo: Jónpáll Pálsson.

6.9.2 Oncorhynchus mykiss (Walbaum, 1792)

The Rainbow trout, *Oncorhynchus mykiss*, (Figure 14) is a Pacific species from the west coast of North America. It has been introduced worldwide for aquaculture and was first transported to Europe in 1884 (MacCrimmon 1971). It was first imported to Iceland from Denmark in 1950 for aquaculture purposes (Gudjonsson 1952). Sea run *O. mykiss* (Steelhead trout) was first recorded in nature in 1983 in the estuary of the Fróðá river, western Iceland (Jónsson 1983). It has since then been observed in rivers and ponds in the Southwest Iceland, as the trout has escaped or been released from hatcheries and fish farms. The size and age of Steelheads caught in South Iceland indicate that they are likely escapees from aquaculture farms in the Faroe Islands. There are no evidences of natural populations in Iceland. However, the possible impact from *O. mykiss* is predation and competition by adults with native species especially brown trout and Arctic charr, fry and parr (Landergren 1999).

Figure 14: Oncorhynchus mykiss

Photo: Alex Borbely.

6.10 Summary and conclusion

Fourteen non-native marine species have been recorded in Icelandic waters in the last 58 years, nine of them in the last decade. This is a diverse group of species belonging to to phytoplankton, macroalgae, crustaceans, bivalves, tunicates and fish. Four of those species can be considered potentially invasive as they adversely affect the habitats and bioregions they invade environmentally, and/or ecologically. The Atlantic rock crab, the brown shrimp and the European flounder are then species that might become invasive in the future, as the populations seems to be healthy and are thriving well in Icelandic waters, spreading rapidly possibly to the disadvantage of other native species.

The brown seaweed *Fucus serratus* is the only macroalgae species that can be classified as an invasive species, as it becomes dominant part of the community by forming a canopy cover in the lower part of the shore, reducing or eliminating the cover of other canopy forming algae.

Other introduced species, still not showing invasive characteristics as the Vase tunicate *Cione intestinalis* and some phytoplankton species as *Mediopyxis helysia*, should be paid attention to in the future as they have become invasive elsewhere in the world where they have been introduced.

The flounder *Platichthys flesus*, the brown shrimp *Crangon crangon* and the Atlantic rock crab *Cancer irroratus*, were first recorded in Icelandic waters in 1999, 2003 and 2006 respectively and all were first found in south-western Iceland. These species spread rapidly, predate on other species in the area and compete for food and space. The brown seaweed *Fucus serratus* that was first observed more than100 years ago, has spread slowly but has outcompeted other native algal species like *Fucus distichus*, where it grows. These species have probably been transported to Iceland in ballast water and in the case of the *Fucus serratus* probably with stone ballast. Most likely they have been transported from Europe, except the rock crab that came from the east coast of North-America. Most of the non-native marine species were first recorded in south-western Iceland where the oceanic traffic of large cargo vessels is most frequent and monitoring programs have been carried out for years.

The increasing sea temperature in Icelandic waters in the last two decades has changed the distribution of local fish species and made it possible for more varied group of non-native species, like the Atlantic rock crab, to invade Icelandic waters.

It is extremely difficult to eradicate non-native marine species once they have arrived. Because of the known risks of certain introductions the emphasis should be on precaution. New regulation on handling of ballast water was introduced in Iceland in 2010 to prevent introduction of alien marine species. It forbids discharge of ballast water in Icelandic jurisdiction. Hopefully this will slow down the rate of new introductions. Although ballast water is certainly an effective vector for transfer of non-native species, other vectors such as ship hull fouling and transport of aquaculture organisms are also important and need to be addressed, but in a different way. The complete prevention of the transport and establishment of non native marine species to Iceland is probably an unrealistic dream. While potentially invasive alien species continue to arrive, understanding the process of settling and establishment of non native species and their effects on the Icelandic coastal ecosystem is necessary. Regular monitoring and case studies are badly needed.

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