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**Research article**

# Alien species in the marine and brackish ecosystem: the situation in Belgian waters

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**Abstract**

In total 61 aquatic alien species (AAS) are known from Belgian marine and brackish waters, eight of which are considered as cryptogenic species. The majority of the Belgian AAS have established self-sustaining populations, although for some species the establishment is uncertain or in need of verification. Prime introduction vectors are shipping, including small recreational craft, and aquaculture. Most AAS originate from the temperate northwest Pacific. The invasion rate has been increasing during the last two decades.

Key words: Belgium, aquatic species introductions, shipping, aquaculture

## Introduction

Worldwide, many species have successfully colonised new habitats as an ongoing phenomenon. Coastal waters are heavily exposed to introductions of alien species as a result of the high intensity of human activities (shipping and organism transplantations for aquaculture purposes) in those regions. Human induced climatic changes also favour the spread and settlement of non-native species outside their normal biogeographical ranges.

Various summaries of aquatic invaders in northwestern European coastal waters exist (Knudsen 1989, Gollasch 1996, Eno et al. 1997, Nehring and Leuchs 1999, Reise et al. 1999, Weidema 2000, Nehring 2005, Jensen and Knudsen 2005, Wolff 2005, Gollasch and Nehring 2006). However, a list of Belgian marine and brackish water invaders was absent.

## Aquatic alien species (AAS) in Belgium

This manuscript addresses marine and brackish water AAS (up to the mesohaline zone) that are well established in Belgian waters, as well as some recognized cryptogenics. In our list we opted for a rather conservative approach, i.e. we did not attempt to prepare an exhaustive list of all species of non-native origin that have ever been recorded in Belgian marine waters, whether established or not. Species that are living

predominantly in freshwater were omitted – although we realize that the selection might be arguable in certain cases – hence well-known invaders such as the zebra mussel *Dreissena polymorpha* (Pallas, 1771) are excluded from our list.

This paper shows that today 61 AAS occur in Belgian marine and brackish waters (including ports). More than 85% of the known introduced species have established self-sustaining populations (Annex). As such, this species group may prove to be a good indicator of ongoing changes. However, some species show an irregular presence. After their introduction and first establishment, they seem to disappear for a period of time before reoccurring again later. Examples are the barnacle *Balanus amphitrite* Darwin 1854 (first recorded in 1952, then again in 1996) and algae, such as *Codium fragile* ssp. *tomentosoides* (van Goor) P.C. Silva 1955, *Polysiphonia senticulosa* Harvey, 1862 and *P. (Neosyphonia) harveyi* J. Bailey, 1848. These species may have required secondary introductions before becoming permanently established, although the reason for this is still unclear. Changing environ-mental conditions such as climate and the continuous building of man made structures may enhance a renewed or definite establishment. For example, the large cosmopolitan barnacle *Megabalanus tintinnabulum* (Linnaeus, 1758) regularly arrived in Belgian marine waters on ships' hulls long before the species finally became established in the late 1990s (Kerckhof and Cattrijsse 2001, WGITMO 2001-2007).

The American blue crab *Callinectes sapidus* Rathbun, 1896 and the Atlantic crocker *Micropogonias undulatus* (Linnaeus, 1766) are now regularly reported in low numbers from the southern North Sea and we have reason to believe that, although not located yet, resident populations may exist in one of the harbours or estuaries. *C. sapidus* individuals collected off the Belgian coast are regularly ovigerous females (Kerckhof and Haelters 2005, WGITMO 2001-2007) and, in the case of *M. undulates*, the otoliths of the young-of-the-year caught in the Netherlands showed no signs of growth retardation, related to stressful transport in ballast water (Dekker et al 2005). This case is further elaborated upon in Nolf and Kerckhof (2007).

Other species, such as the barnacles *Balanus variegatus* Darwin, 1854, *B. reticulatus* Utinomi, 1967, *B. trigonus* Darwin, 1854, the bryozoan *Bugula neritina* (Linnaeus, 1758) and the tunicate *Botrylloides violaceus* Oka, 1927 are still in the process of becoming established in Belgian marine waters. Some species clearly take advantage of the improved water quality to become more abundant after decades of being nearly absent. Examples are the Chinese mitten crab *Eriocheir sinensis* (H. Milne-Edwards, 1853) (Mares 1995, WGITMO 2001-2007) and the false dark mussel *Mytilopsis leucophaeata* (Conrad, 1831) (Verween 2007).

An interesting case is the large brown algae *Sargassum muticum* (Yendo) Fensholt, 1955. Although fertile fragments have been found on Belgian beaches since 1972, often in large quantities (Coppejans et al. 1980), it took until 1999 (Zeebrugge) and 2000 (Sluice Dock, Oostende) until its autochthonous presence could be proven. During the years 2002 to 2004 it was apparently not present on the latter site, but reappeared in 2005 and 2006. Meanwhile *Sargassum* spread further in the Zeebrugge inner harbour (pers. observation).

### *An early introduction: Mya arenaria*

Probably the earliest known introduction in Belgium – as elsewhere in northern Europe – is the soft-shell clam *Mya arenaria* (Linnaeus, 1758). Because of the absence of fossils, this species was thought to have been introduced from the American east coast during the 16$^{th}$ or 17$^{th}$ century (Hessland 1946). However, Petersen et al. (1992) present evidence of an earlier introduction to Europe, before 1245-1295. These authors suggested a transfer by the Vikings, a hypothesis questioned by Wolff (2005).

Our research found that *M. arenaria* was absent in the Belgian coastal region during medieval ages (e.g. Kerckhof 1995), yet around Oostende, *M. arenaria* was common in the 19$^{th}$ century. Forbes and Hanley (1853) mention the presence of distorted specimens in the Cuming collection, originating from the sluices at Oostende. We also found specimens in sediment excavated from the moats surrounding the ancient city of Oostende, which were constructed in the 18$^{th}$ century and filled up around 1865. Furthermore, we found high abundances of this species in some of the 13 historical polders surrounding the city of Oostende. When inundated with seawater, this lowland served to sluice the harbour, and the polders were used at various time intervals from 1584 -1810 (Farasijn

2006). *M. arenaria* was, for example, plentiful in the Snaaskerke Polder, in use between 1721 and 1810, and also in the connected Keignaeart Polder, which was used at approximately the same period. We could, however, not ascertain the presence of *M. arenaria*, in the other polders. During the 18th century, Oostende had several flourishing trading contacts with North America and the Baltic states. Interestingly, the earliest record of this species in the Netherlands, Zierikzee (Baster 1765), dates from approximately the same period. Nowadays, *M. arenaria* is still a common inhabitant of the Belgian harbours and estuaries.

### *Effects of AAS on the marine ecosystem*

Changes in the nearshore Belgian benthic communities due to non-native species were particularly remarkable during the past two decades (Figure 1).

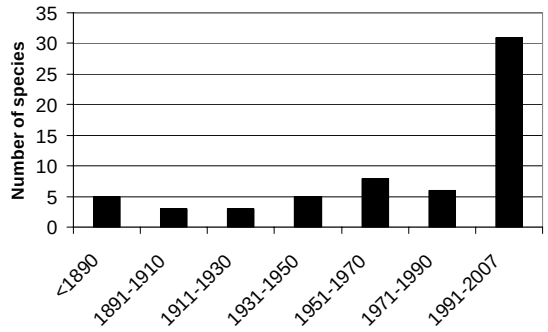


*Figure 1.* Number of aquatic alien species introductions into Belgian coastal waters over 20 year intervals between 1850 and 2007

Four species, namely the American jack-knife clam *Ensis directus* (Conrad 1843), the pacific oyster *Crassostrea gigas* (Thunberg, 1793), the New Zealand barnacle *Elminius modestus* Darwin, 1854 and the slipper limpet *Crepidula fornicata* (Linnaeus, 1758) now constitute a dominant part of the Belgian marine nearshore fauna. These species are invasive, competing with native species, changing the original habitat and significantly altering the overall biodiversity and biomass.

After its first observation in Belgium in 1987, *E. directus* rapidly colonised all coastal sandy sediments (Kerckhof and Dumoulin 1987). Nowadays, the shells and dying specimens of this species are frequently washed onto the Belgian beaches in millions (Figure 2). Almost simultaneously, but predominantly on hard substrates, we have witnessed the massive establishment of *C. gigas*, now forming extensive reefs (Figure 3). Although introduced in the 1970s for mariculture purposes, *C. gigas* only became established outside areas of cultivation in the early 1990s, most likely due to an increase of water temperatures.

*Figure 2. Ensis directus* washed ashore at Koksijde beach, April 2005. Photo courtesy of MUMM.

*Figure 3.* Massive reefs of *Crassostrea gigas* at Nieuwpoort, January 2005. Photo courtesy of MUMM

A striking example of species that take advantage of the new opportunities created by man, are sessile barnacles (Cirripedia Balanomorpha). *E. modestus* is now the most common barnacle. This species was probably introduced in the 1940s and today it is very common on all

types of artificial substrata in the intertidal and shallow subtidal zone.

The slipper limpet *C. fornicata*, which is another early introduction, recently increased in numbers. This species was introduced into Europe from North America at the end of the 19th century. In Belgian waters it has been present from at least 1911 onwards. *C. fornicata* is now extremely common, not only on hard substrata, but also on soft sediments where it lives attached to substrata, such as empty shells, and displays a similar feeding ecology as bivalves. In the latter habitat, it has recently undergone a renewed expansion, a feature also noted along other western European coastal waters (e.g. in France and The Netherlands). It is thought that bottom trawling practices favour the further expansion of this species (de Montaudouin et al. 2001).

*Figure 4.* The barnacles *Megabalanus coccopoma, Balanus perforatus* and *Elminius modestus* on the Westhinderbuoy, December 2006. Photo courtesy of MUMM.

Offshore buoys form a particular habitat. We recorded a number of non-native species (Figure 4), such as the chironomid *Telmatogeton japonicus* Tokunaga, 1933 and the barnacles *Megabalanus tintinnabulum*, *M. coccopoma* (Darwin, 1854), *Balanus reticulatus*, *B. trigonus* and *B. variegatus* mainly from buoys off the Belgian coast (Kerckhof and Cattrijsse 2001, WGITMO 2004-2007). Further, our investigation indicated that buoys support several other well-known AAS such as the caprellid amphipod *Caprella mutica* Schurin, 1935, the pacific oyster *Crassostrea gigas*, the barnacle *Elminius modestus* and gastropod *Crepidula fornicata.* The named species form thriving populations, even on buoys far offshore. This illustrates that man-made floating structures may act as stepping stones in the establishment and spreading of non native species.

### *Case study: the Sluice Dock at Oostende*

An interesting habitat for AAS is the so-called Sluice Dock at Oostende (Figure 5). This is an artificial pond of 86 ha, excavated around 1900 and originally intended for cleaning the harbour. However, it failed to serve this purpose. The Sluice Dock was subsequently used for aqua-culture, i.e. for cultivating and/or relaying of oysters and other shellfish from the 1930s till World War II and again from 1957 onward, with a peak during the 1960s and early 1970s. In 1974 oyster cultivation was halted temporarily due to bad water quality (eutrophication).

*Figure 5.* Aerial view of the Sluice Dock at Oostende. Photo courtesy of MUMM

The Sluice Dock has a variable salinity and periodically stands dry. Next to huge imports of native oysters *Ostrea edulis* Linnaeus, 1758 from all over Europe, there was a massive import of American oysters *Crassostrea virginica* (Gmelin, 1791), originating from the east coast of the United States (1930s until 1972), and also of so-called Portuguese oysters, '*C. angulata*' (Lamarck, 1819). originating from southern Europe (e.g. Leloup and Polk 1967, Leloup et al. 1965, Leloup 1971, 1973, 1980, Georges Halewyck pers. com.). '*C. angulata*' has been shown to be the same species as *C. gigas*, a

strain originating from Taiwan, from where it was introduced into Portugal (e.g. Menzel 1974, Boudry et al. 1998). Later, in 1969 and the early 1970s, *C. gigas* was imported into the Sluice Dock, mainly as a secondary introduction from the Netherlands (Leloup 1971). These Dutch specimens had direct Pacific (Japanese and/or Canadian) roots and had been deliberately introduced in The Netherlands after the cold and disastrous winter of 1964 (see Wolff 2005). Other imported and relayed shellfish include the clams *Ruditapes philippinarum* (Adams & Reeve, 1850) and *Mercenaria mercenaria* (Linnaeus, 1758). The only species apparently able to establish self-sustaining populations here is *C. gigas* (Curé et al. 2002, pers. observations). Specimens survived even after the cessation of oyster cultivation and import activities in 1974. Nowadays *C. gigas* forms large reefs on the floor and the borders of the dock. Interestingly the so-called Portuguese oysters, although able to become gravid, never spawned (Leloup and Polk 1967, Georges Halewyck pers com), probably because they originated from southern Europe (Portugal, Spain) and were unable to adapt to the colder conditions in Belgium.

In 1996, some shellfish activities resumed in the Sluice Dock and are still ongoing albeit on a less intensive scale, with imports of oysters (*Ostrea edulis, Crassostrea gigas*) and other shellfish (e.g. *T. philippinarum, M. mercenaria*) from all over Europe and now also from Canada (Curé et al.2002, WGTIMO 2001-2007).

It is clear that all these movements of shellfish result in frequent and repeated introductions of many AAS. Indeed our research indicates that nearly half of the species mentioned in the Annex are known to occur in the Sluice Dock.

Many species, which were occasionally introduced into the Sluice Dock, survived for a short period of time, but never formed stable populations. Examples of a southern European origin (Atlantic or Mediterranean) include the molluscs *Haminea navicula* (Da Costa 1778), *Anomia ephippium* Linnaeus, 1758, *Calyptraea chinensis* (Linnaeus, 1758) and Aporrhais *pespelicani* (Linnaeus, 1758) (e.g. Leloup and Polk 1967; Kermarrec-Labisse 1968). Another example is the hydrozoan *Gonionemus vertens* A. Agassiz, 1862. Leloup (1948) observed this species in 1946 and 1947 but it has never been recorded since, although this particular species still survives in suitable habitats in the Netherlands (Wolff 2005). Interestingly, even species not directly related to aquaculture activities, such as the bivalves *Ensis directus, Mya arenaria, Petricola pholadiformis* Lamarck, 1818 and the bryozoan *Bugula stolonifera*, Ryland, 1960 entered into the Sluice Dock and managed to survive.

*Recently discovered AAS*

To further illustrate the fact that non-indigenous species are still being introduced into the southern North Sea, we list the latest examples of new records for Belgian waters. These include the macroalgae *Polysiphonia (Neosiphonia) harveyi* (2000) and *P. senticulosa* (2001), the bryozoans *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985 and *Bugula simplex* Hincks, 1886 (2000), the chironomid *Telmatogeton japonicus* (2005), the crabs *Hemigrapsus takanoi* Asakura & Watanabe, 2005 (2003) and *H. sanguineus* (De Haan, 1835) (2006) and the prawn *Palaemon macrodactylus* Rathbun, 1902 (2004). At the moment of their discovery, these species were already common. The case of the *Hemigrapsus* species is particularly intriguing, because both species are now so numerous in all sorts of habitats, intertidal as well as shallow subtidal, that an effect on local species composition is almost inevitable, resulting in possible species shifts, in particular of the resident crab fauna.

The veined whelk *Rapana venosa* (Valenciennes, 1846), a voracious predator, has been reported twice in the southern North Sea. This Asian gastropod is a well known invader in the Black and Adriatic Seas and was also found along the Atlantic coast of France. In 2005, it was found approximately halfway between Harwich and Oostende (Kerckhof et al. 2006). As this record was outside the Belgian waters, this species is not included in the list provided here. However, the species may already be present in Belgian waters.

One of the most recent new findings in Belgium is *Rangia cuneata* (G. B. Sowerby I, 1831), a bivalve native to the Gulf of Mexico and the Atlantic coast of North America. This estuarine species was recorded in the cooling water pipes of an industrial plant in the Port of Antwerp from February 2005 onwards (Verween et al. 2006). It is the first record of this species, not only for Belgium, but also for Europe. However, our observations show that *R. cuneata* was already present in the harbour of Antwerp several years prior to its first reporting.

Only when it became a nuisance did we became aware of its presence. Our recent research efforts revealed the presence of a large and thriving population in the Verrebroekdok, one of the larger docks of the harbour of Antwerp with mesohaline water conditions. During a survey in May 2007, living *Rangia* specimens from several year classes were found (Kerckhof, unpublished). The adult individuals present, being at least six years old, indicate that the species almost immediately colonised the dock after its opening in 2000. This particular dock receives high volumes of traffic from the north east coast of the United States. Other AAS were found to co-occur with *Rangia,* e.g. the crabs *Eriocheir sinensis*, *Rhithropanopeus harrisii* (Gould, 1841) and the false dark mussel *Mytilopsis leucophaeata* (Kerckhof, unpublished).

Finally, the newest invader is the American ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865 found in the port of Zeebrugge in 2007. It was probably introduced with ballast water from North America and was already very abundant at the time of its discovery. It could also have spread from the nearby established populations in the Netherlands (Dumoulin 2007).

### *Cryptogenic species*

For many species the invasion status is unknown, i.e. they are either introduced or native (Carlton 1996) and although there may be indications that some cryptogenic species are of foreign origin, it is often difficult to assess their true status. We list eight species of uncertain invasion status: the barnacle *Balanus improvisus* Darwin, 1854, the amphipod *Corophium (Monocorophium) sextonae* (Crawford 1937), the woodboring bivalves *Teredo navalis* Linneaus, 1758 and *Psiloteredo (Teredo) megotara* (Hanley in Forbes & Hanley 1848), the hydrozoan *Garveia franciscana* (Torrey, 1902), the polychaete *Marenzellaria viridis* (Verrill, 1873) and the bryozoan *Bugula stolonifera*. As those species may have been introduced, they were included in the Annex for the purpose of comparison.

### *Potential vectors*

As for the most recent AAS introductions, the prime introduction vectors are shipping, including small recreational crafts, and species imported for aquaculture (Figure 6). The dominating native range of the AAS listed above is the temperate Northwest Pacific (Figure 7). However, it is most likely that many AAS reached the Belgian coast through secondary spread from neighbouring countries. There is a real danger that exotic plants and animals bring with them all sorts of associated organisms or diseases which may also affect native species. For instance, oysters imported from Japan carried the single-celled parasite *Bonamia ostreae* (Pichot et al., 1979) which is also harmful to indigenous oysters. The introduction of other micro-organisms, such as phytoplankton taxa, may cause blooms of harmful algae, making oysters or mussels periodically unsuitable for human consumption, or causing loss of harvest in aquaculture, due to the death of cultured species.

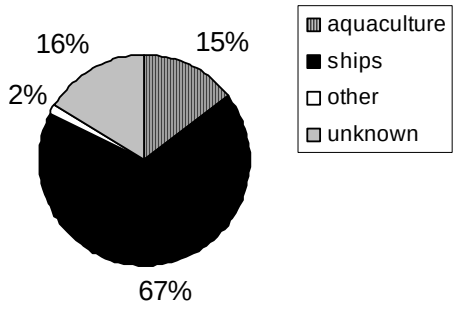


*Figure 6.* Introduction vectors of aquatic alien species in Belgian coastal waters.

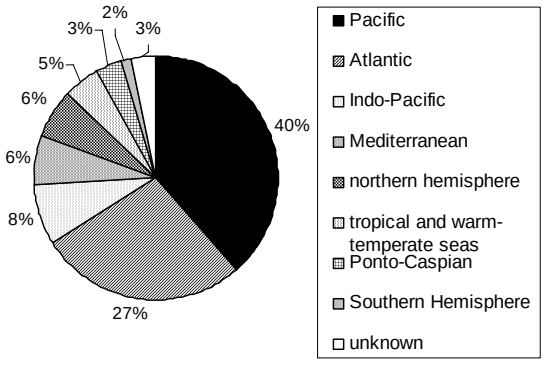


*Figure 7.* Source regions of aquatic alien species in Belgian coastal waters.

## Aquatic alien species introductions in Belgium: the future

Like in so many regions, the rate of invasion of AAS has increased in Belgium during the last two decades. Most of the Belgian newcomers prefer environments created by man or that are heavily influenced by man, such as harbours (marinas) and nearshore coastal areas. Here, numerous artificial hard substrata are available in the otherwise sandy sediment which dominates the Belgium coastline. Such areas are, therefore, highly suitable for relatively undemanding immigrants which are able to outcompete the indigenous flora and fauna, although some of them can also take advantage of empty niches. So far, there are no clear examples of species extinctions in the North Sea due to the introduction of AAS, although the original distribution area of indigenous species may have been greatly reduced. Therefore, even if introduced species may locally increase the biodiversity, they might provoke the impoverishment of biodiversity on a larger, even worldwide scale.

However, despite the obvious effects on the whole nearshore environment, introduced species in Belgian marine waters are currently of no great public concern, as they are currently not regarded as causing serious threats or economic damage.

The Belgian law of 20 January 1999 on the protection of the marine environment in the marine areas under Belgian jurisdiction prohibits the intentional introduction of non-indigenous species in the marine environment. Unfortunately, this provision does not apply to inland marine waters like the Sluice Dock. On an international level, the invasion rate of ballast water mediated AAS introductions is hopefully reduced by new management regulations which are currently under development.

In the meantime the introduction of alien species in Belgium is being monitored on an ad-hoc basis. Their introduction vectors and impact on the environment and on native fauna and flora is being noted whenever possible.

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## *Annex*

Aquatic alien species reported from Belgian coastal areas

| Species | Date and location of first autochthonous record | Status | Native range | Vector/ Pathway | Impact (known and expected) | References |
|---|---|---|---|---|---|---|
| **Protista** | | | | | | |
| *Bonamia ostreae* (Pichot et al., 1979) | after 1979, Sluice Dock, Oostende | alien, establishment uncertain | Pacific | aquaculture unintentionally | parasite | ICES 2007 |
| Phytoplankton | | | | | | |
| **Bacillariophyceae** | | | | | | |
| *Coscinodiscus wailesii* Gran et Angst, 1931 | after 1977, marine plankton | alien | Indo-Pacific | unknown | blooming | Edwards et al 2001, Laing and Gollasch 2002 |
| *Odontella sinensis* (Greville) Grunow, 1884 | 1904, marine plankton | alien | Indo-Pacific | ships | blooming | Ostenfeld 1908 |
| *Thalassiosira punctigera* (Castracane) Hasle, 1983 | 1993, Westerschelde estuary | alien | Indo-Pacific | unknown | blooming | Muylaert and Sabbe 1996 |
| Macrophytes | | | | | | |
| Macroalgae | | | | | | |
| **Rhodophyceae** | | | | | | |
| *Antithamnionella spirographidis* (Schiffner) E.M.Wollaston, 1968 | 1992, Zeebrugge and Oostende | alien | N Pacific | ships | unknown | Coppejans 1998, WGTIMO 2001, Wallentinus 2007 |
| *Antithamnionella ternifolia* (C. Agardh) Nägeli, 1847 , (as *A. sarniensis*) | 1970, Sluice Dock, Oostende | alien | Southern hemisphere | ships | unknown | Leloup 1973, Coppejans 1995, Wallentinus 2007 |
| *Polysiphonia senticulosa* Harvey, 1862 | 2001, Sluice Dock, Oostende | alien | N Pacific | aquaculture unintentionally | unknown | Kerckhof and Stegenga 2003 |
| *Polysiphonia (Neosiphonia) harveyi* Bailey, 1848 | 2000, Sluice Dock, Oostende | alien | N Pacific, NW Atlantic | ships | unknown | Kerckhof unpublished, Maggs and Stegenga 1999 and reference therein, Wallentinus 2007 |
| **Phaeophyceae** | | | | | | |
| *Sargassum muticum* (Yendo) Fensholt, 1955 | 1999, Zeebrugge, 2000 Sluice Dock, Oostende | alien | NW Pacific | aquaculture unintentionally, | fouling, competition | De Blauwe 2000, WGITMO 2001-2007 |
| Undaria pinnatifida (Harvey) Suringar, 1873 | 1999, marina Zeebrugge | alien | NW Pacific | aquaculture intentionally, in Belgium secondary by ships | fouling, competition | Dumoulin and De Blauwe 1999, WGITMO 2001-2007 |
| **Chlorophyceae** | | | | | | |
| *Codium fragile ssp. tomentosoides* (van Goor) P.C. Silva 1955 | 1939, Sluice Dock, Oostende | alien, establishment uncertain | NW Pacific | aquaculture unintentionally | competition | Leloup and Miller 1940, WGITMO 2001-2007, Wallentinus 2007 |
| **Tracheophyta** | | | | | | |
| **Poaceae** | | | | | | |
| *Spartina townsendii var. Anglica* Hubbard, 1968 | 1920s, Westerschelde estuary | alien | N America x Europe | intentionally, other | unknown | Vanhecke 2006 |

| Species | Date and location of first autochthonous record | Status | Native range | Vector/ Pathway | Impact (known and expected) | References |
|---|---|---|---|---|---|---|
| **Animalia** | | | | | | |
| **Cnidaria** | | | | | | |
| **Hydrozoa** | | | | | | |
| *Cordylophora caspia* (Pallas, 1771) | 1905, Nieuwpoort | alien | Ponto-Caspian | unknown | unknown | Loppens 1905, Leloup 1952 |
| *Garveia franciscana* (Torrey, 1902) | 1956 (as *Bougainvillia ramosa*?) / 1962, both Westerschelde Estuary near Doel and Liefkenshoek | cryptogenic | Indo-Pacific? | unknown | unknown | Leloup and Konietzko 1956, Vervoort 1964 |
| *Nemopsis bachei* L. Agassiz, 1849 | 1996, Port of Zeebrugge | alien | NW Atlantic | ships | unknown | Dumoulin 1997, WGITMO 2006 |
| **Anthozoa** | | | | | | |
| *Haliplanella lineata* (Verrill, 1869) | 1998, Sluice Dock, Oostende | alien | NW Pacific | ships | unknown | Kerckhof unpublished, WGITMO 2001 |
| **Ctenophora** | | | | | | |
| *Mnemiopsis leidyi* A. Agassiz, 1865 | 2007, Port of Zeebrugge | alien | NW Atlantic | ships | competition predation, invasive | Dumoulin 2007, Faasse and Bayha 2006 |
| **Annelida** | | | | | | |
| **Oligochaeta** | | | | | | |
| *Tubificoides heterochaetus* (Michaelsen, 1926) | 1953, Westerschelde estuary | cryptogenic | NW Atlantic? | unknown | unknown | Konietzko 1953 Seys, J. et al 1999 |
| **Polychaeta** | | | | | | |
| *Ficopomatus enigmaticus* (Fauvel, 1923) | <1952, Port of Oostende | alien | Indo-Pacific | ships | fouling | Leloup and Lefevere 1952, WGITMO 2001-2007 |
| *Polydora hoplura* Claparède, 1870 | 1962, Sluice Dock, Oostende | alien, establishment uncertain | NE Atlantic | aquaculture unintentionally | fouling, blister forming in oysters | Leloup and Polk 1967 |
| *Marenzelleria viridis* (Verrill, 1873) | 1996, Doel Westerschelde estuary | cryptogenic | NW Atlantic | ships | unknown | Ysebaert et al 1997 |
| **Crustacea** | | | | | | |
| **Cirripedia** | | | | | | |
| *Balanus amphitrite* Darwin, 1854 | 1952, Port of Oostende, 1995 Koksijde | alien | Mediterranean, tropical | ships | fouling, competition | Kerckhof 1996, Kerckhof and Cattrijsse 2001 |
| *Balanus improvisus* Darwin, 1854 | <1700, marine and inshore waters | cryptogenic | W Atlantic | ships | fouling, competition | Kerckhof and Cattrijsse 2001 |
| *Balanus trigonus* Darwin, 1854 | 1997, on offshore buoys | alien, establishment uncertain | tropical and warm-temperate seas | ships | unknown | Kerckhof and Cattrijsse 2001 |
| *Balanus reticulatus* Utinomi, 1967 | 1997, on offshore buoys | alien | tropical and warm-temperate seas | ships | unknown | Kerckhof and Cattrijsse 2001 |
| *Balanus variegatus* Darwin, 1854 | 1997, on offshore buoys | alien, establishment uncertain | Indo-Pacific | ships | unknown | Kerckhof and Cattrijsse 2001 |
| *Elminius modestus* Darwin, 1854 | 1950, hull coastal research vessel | alien | Austral-Asia | ships | fouling, competition invasive | Leloup and Lefevere 1952, Kerckhof and Cattrijsse 2001, Kerckhof 2002 |

| Species | Date and location of first autochthonous record | Status | Native range | Vector/ Pathway | Impact (known and expected) | References |
|---|---|---|---|---|---|---|
| *Megabalanus coccopoma* (Darwin, 1854) | 1997, offshore buoys | alien | Tropical eastern Pacific coasts of Central and South America | ships | fouling, competition | Kerckhof and Cattrijsse 2001, WGITMO 2001-2007 |
| *Megabalanus tintinnabulum* (Linnaeus, 1758) | 1998, offshore buoys | alien | tropics | ships | fouling, competition | Kerckhof and Cattrijsse 2001, WGITMO 2001-2007 |
| **Copepoda** | | | | | | |
| *Acartia tonsa* Dana, 1849 | 1956, Westerschelde estuary | alien | Indo-Pacific | ships | unknown | Leloup and Konietzko 1956, Leloup and Polk 1967, Tackx and Polk 1982, Tackx et al 2004 |
| *Eurytemora americana* Williams, 1906 (as *E. affinis*) | 1938, Sluice Dock, Oostende | alien | NW Atlantic | ships | unknown | Leloup and Miller 1940, Polk 1977 |
| *Mytilicola intestinalis* Steuer, 1902 | 1950, Knokke Zoute, Heist, Zeebrugge | alien | Mediterranean | aquaculture unintentionally | parasite | Leloup 1951 |
| **Mysidacea** | | | | | | |
| *Hemimysis anomala* Sars, 1907 | 1999, Galgenweel Antwerp | alien | Ponto-Caspian | unknown | unknown | Verslycke et al 2000 |
| **Amphipoda** | | | | | | |
| *Caprella mutica* Schurin, 1935 | 1998, buoys in the (larger) vicinity of the harbour of Zeebrugge and Zeebrugge harbour | alien | NW Pacific | ships | fouling, competition | Kerckhof; unpublished WGITMO 2001-2007 |
| *Corophium (Monocorophium) sextonae* (Crawford 1937) | <2000, offshore wrecks | cryptogenic | S Pacific | unknown | unknown | Massin et al 2002 |
| *Gammarus tigrinus* Sexton, 1939 | 1995, Grote Put Antwerp-Ekeren | alien | N America | unknown | unknown | Wouters 2002, Belgian Biodiversity Platform 2006 |
| *Incisocalliope aestuarius* (Watling and Maurer, 1973) (as *Pleusymtes glaber*) | <1991, Westerschelde estuary | alien | NW Atlantic | ships | unknown | Ysebaert et al 2000, Faasse and van Moorsel 2003 |
| **Decapoda** | | | | | | |
| *Callinectes sapidus* Rathbun, 1896 | 1981, Belgian coast, Westerschelde estuary | alien | NW Atlantic (Nova Scotia to Uruguay) | ships | predation | Adema 1991, Maes et al 1998, WGITMO 2001-2007 |
| *Eriocheir sinensis* (H. Milne-Edwards, | 1933, Kruisschans Antwerp, 1934 Nieuwpoort | alien | NW Pacific | ships | habitat alteration, predation, invasive | Lestage 1935, Wouters 2002 |
| *Hemigrapsus sanguineus* (De Haan, 1835) | 2006, Knokke-Heist, Nieuwpoort | alien | NW Pacific | ships | Competitio npredation | d'Udekem d'Acoz 2006, Nuyttens et al 2006 |

| Species | Date and location of first autochthonous record | Status | Native range | Vector/ Pathway | Impact (known and expected) | References |
|---|---|---|---|---|---|---|
| *Hemigrapsus takanoi* Asakura & Watanabe, 2005 | 2003, Oostende, Zeebrugge, Westerschelde estuary | alien | NW Pacific | ships | competition predation, invasive | Dumoulin 2004, WGITMO 2004-2007 |
| *Palaemon macrodactylus* Rathbun, 1902 | 2004, marina Zeebrugge | alien | NW Pacific | ships | unknown | d`Udekem d`Acoz et al 2005 |
| *Rhithropanopeus harrisii* (Gould, 1841) | 1985, Westerschelde estuary near Antwerp | alien | NW Atlantic (Nova Scotia to Mexico) | ships | competition predation | Dumoulin and Rappé 1985, Maes et al 1998, Ysebaert et al 2000, Wouters 2002, Adema 1991 |
| **Insecta** Chironomidae, Diptera | | | | | | |
| *Telmatogeton japonicus* Tokunaga, 1933 | <2005, buoys off the Belgian coast | alien | NW Pacific | ships | unknown | Kerckhof; unpublished WGITMO 2005, 2006 |
| **Bryozoa** | | | | | | |
| *Bugula neritina* (Linnaeus, 1758) | 1999, marina Oostende | alien, establishment uncertain | Mediterranean ? | ships | unknown | Kerckhof 2000 |
| *Bugula simplex* Hincks, 1886 | 2000, marina Oostende | alien | Mediterranean ? | ships | unknown | Kerckhof 2000, 2001 |
| *Bugula stolonifera* Ryland, 1960 | 1999, marina Oostende | cryptogenic | NW Atlantic | ships | fouling, competition | Kerckhof 2000 |
| *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985 | 2000, Oostende and Blankenberge, marinas | alien | Pacific | ships | fouling | De Blauwe and Faasse 2001, WGITMO 2001-2007 |
| **Mollusca Gastropoda** | | | | | | |
| *Crepidula fornicata* (Linnaeus, 1758) | 1911, Oostende, on an imported (English?) flat oyster | alien | NW Atlantic | aquaculture unintentionally | habitat alteration, fouling, competition invasive | Adam and Leloup 1934, Polk 1962, Fretter and Graham 1981, Belgian Biodiversity Platform 2006 |
| *Potamopyrgus antipodarum* (Gray, 1843) | 1927, Schelde estuary near Antwerp | alien | New Zealand | ships | unknown | Dupuis 1927, Adam 1960 |
| **Bivalvia** *Crassostrea gigas* (Thunberg, 1793) | 1969, Sluice Dock, Oostende | alien | Japan and SE Asia | aquaculture intentionally | habitat alteration, fouling, competition parasite carrier, invasive | Leloup 1971, Kerckhof 1997, WGITMO 2001 - 2007 |
| *Ensis directus* syn. *E. americanus* (Conrad 1843) | 1986, Oostduinkerke, Zeebrugge | alien | NW Atlantic | ships | competition invasive | Kerckhof and Dumoulin 1987, Beukema and Decker 1995 |
| *Mya arenaria* (Linnaeus, 1758) | <1700, inshore waters and harbours | alien | NW Atlantic | ships | unknown | Backeljau 1986 |

| Species | Date and location of first autochthonous record | Status | Native range | Vector/ Pathway | Impact (known and expected) | References |
|---|---|---|---|---|---|---|
| *Mytilopsis leucophaeata* (Conrad, 1831) | 1835, Schelde estuary at Antwerp | alien | NW Atlantic | ships | fouling, competition | Nyst 1835, Adam 1960, Marelli and Gray 1983, WGITMO 2001-2007 |
| *Petricola pholadiformis* Lamarck, 1818 | 1899, Nieuwpoort | alien | NW Pacific | aquaculture unintentionally | competition | Loppens 1902 |
| *Rangia cuneata* (G. B. Sowerby I, 1831) | <2000, Port of Antwerp | alien | Gulf of Mexico, NW Atlantic | unknown, ships? | fouling, habitat alteration, clogging of water intake pipes | Kerckhof unpublished; Verween et al. 2006 |
| *Teredo (Psiloteredo) megotara* (Hanley in Forbes & Hanley 1848) | <1600, coastal waters and harbours | cryptogenic | unknown | ships | habitat alteration | Backeljau 1986 |
| *Teredo navalis* Linneaus, 1758 | <1600, coastal waters and harbours | cryptogenic | unknown | ships | habitat alteration | Backeljau 1986 |
| **Chordata** | | | | | | |
| **Tunicata, Ascidiacea** | | | | | | |
| *Botrylloides violaceus* Oka, 1927 | 2004, Zeebrugge, Sluice Dock, Oostende | alien | NW Pacific | ships | unknown | De Blauwe unpublished, Kerckhof unpublished |
| *Styela clava* Herdman, 1882 | <1986, Knokke Heist | alien | NW Pacific | ships | fouling, habitat alteration | d`Udekem d`Acoz 1986 |
| **Vertebrata** | | | | | | |
| **Pisces** | | | | | | |
| *Micropogonias undulatus* (Linnaeus, 1766) | 1998, off the Belgian coast, Westerschelde estuary | alien | NW Atlantic | ships | unknown | Rappé 2002, Stevens et al 2004, WGITMO 2001-2007 |