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**Research article**

# A checklist of alien and cryptogenic aquatic species in Ireland

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## Abstract

One-hundred-and-twelve alien species are recorded for marine, brackish and freshwater environments in Ireland, of these sixty-eight are thought to be established. Their arrival has been mainly due to shipping, aquaculture and the ornamental industries. There are almost thirty species considered to be invasive and some that have arrived recently may have significant future impact. The majority of recorded alien species will have arrived since 1950. Usually these species appear in Britain or Northern Europe before occurring in Ireland. The majority of the marine species will have originated from the North Pacific Ocean whilst most of the freshwater species will have originally been sourced from North America. The sixty-three cryptogenic species arise out of the uncertainty of their origin or as to how they will have arrived. Ireland being a recently deglaciated island and separated from the continental land mass will have acquired the majority of its biota since the last glacial retreat making distinction between native and alien species more difficult.

*Key words*: Ireland, Celtic Sea, aquatic species, introductions, alien, freshwater, marine, invasive, population status

## Introduction

The spread of alien species arises out of centuries of human mobility aided by increased trade over progressively greater areas via new vector transmissions and further and more rapid routes for dispersal (Minchin 2006a, 2007a). Trade in Ireland up till the early 1900s was mainly confined to Britain, Northern Europe, and the eastern coast of North America. Today links exist with all continental regions and aliens may be directed through Northern Europe or Britain and then subsequently spread as a result of natural range extensions and/or by human transmissions to Ireland.

There have been compilations of alien species for Ireland for some taxonomic groups (Hayden 2002, Reynolds 2002), environments (O'Riordan 2002) or as a result of specific industries (Minchin 1996, 2004). No previous attempt has been made to include all known alien aquatic species from the freshwater, brackish (transitional) and marine environments of Ireland or to separate them according to alien and cryptogenic components. However, a full list of aquatic aliens is unlikely to be achieved as this requires specific taxonomic knowledge, regular monitoring to reveal them and many are either or both rare or cryptic and remain undiscovered. Those that become recognised are normally because they are either conspicuous or result in some recognised impact. Alien species are defined here as those species that will have been spread intentionally or unintentionally by humans to areas outside of their natural range. Any subsequent movements may either involve humans or natural spread or combinations of both. While many can be recognised as aliens there is a significant component whose means of arrival, or whose native origin, is unclear or

unknown. These are termed cryptogenic species (Carlton 1996). In time the origin and history of some of the cryptogenic component will be clarified though forensic biogeography. Very often species that arrive in Ireland will have been recorded at an earlier time in Britain (Minchin and Eno 2002) or elsewhere in northern Europe. Shipping, aquaculture and the trade in ornamentals has enabled the spread of species over greater distances, and from different geographical provinces. The extent and reduced durations of long-distance transport have greatly aided opportunities for the dispersal of species (Minchin 2006a, Minchin 2007a). In concert with this increased trade and mobility there are many well studied regions of the world showing an increase in the frequency of alien species arrivals in recent decades (Hewitt et al. 1999, Cohen and Carlton 1998, Leppäkoski et al. 2002, Wonham and Carlton 2005, Leppäkoski and Olenin 2000).

This account summarises the occurrence of those aquatic species that have been recorded in Ireland to June of 2007. The list ranges from single records of species, some of which are unlikely to survive or become established in Irish waters, to those that are invasive and spreading. The account does not provide a full record of alien microbiota and disease organisms. Similar recent European accounts have been compiled for Belgium (Kerckhof et al. 2007), Denmark (Jensen and Knudsen 2005), Germany (Gollasch and Nehring 2006), The Netherlands (Wolff 2005), the Baltic States (Olenin 2005) and the Ukraine (Alexandrov et al. 2007).

## Methods

A register of alien and cryptogenic species was developed from literature searches through journals, reports, unpublished records and from recent field and taxonomic studies.

There are different levels of certainty as to how a species arrives (Minchin 2007a). In cases where there is direct evidence for an arrival the activity responsible for the arrival is known. Likely arrivals are those associated with a vector activity in an area adjacent to where a species is presumed to have arrived and where there is also evidence for the species being associated with the same mode of entry elsewhere. Written accounts that relate to early introductions are also considered. In many cases direct evidence is lacking and no single likely mode can be ascribed. Possible modes for an entry, where several activities may be responsible for an introduction, are not considered in assessments of the role of human activities in the introduction of species except in a group analysis of all possible entry modes.

Species living adjacent to aquatic environments without a dependency on water immersion are not considered in this account, such as riverbank plants and mammals (with one exception) and all birds. Neither are vagrant species arriving as a result of climate or ocean currents such as plant disseminules (Nelson 2000), however, some molluscs arriving on drifting man-made objects have been included.

Cryptogenic species are tabled separately (Annex 2). Over time the status of some of these is expected to change and so may be removed due to improved knowledge of natural dispersal mechanisms or of transport from their origin.

## Results

One-hundred-and-twelve alien species were found in Ireland (Annex 1) and sixty-three cryptogenic species (Annex 2). The numbers obtained show an increase of both marine and freshwater species recorded for recent decades (Figure 1). The most notable increase is from the 1950s to the present day. While there are fewer cryptogenic species these generally show a similar trend except over the last seventeen-year period (Figure 2). The arrival of eighteen species prior to 1850 can not be truly ascribed as being native or alien either due to imperfect knowledge of their native distributions or as to how they arrived.

The great majority of marine species originate from the North Pacific and if extended to include the Indo-Pacific would make up more than half of all records (Figure 3). Among these are deliberate introductions for aquaculture made-up of five cultivated molluscs and a fish making up ~10% of this total. Over twenty percent of the brackish and marine species are from the north-west Atlantic arriving as a result of the close trading connection between the east coast of North America and Britain and Ireland. This same historical link, over the last few hundred years, could explain the large proportion of freshwater biota, of more than one third, arriving from North America (Figure 4). As far as can be reasonably determined the great majority of species will have arrived with aquaculture, trade

in ornamental species and with commercial and leisure vessels (Figure 5) with most arriving within the last fifty years. Natural spread of aliens will have involved either the spread of molluscs attached to buoys and other human-made flotsam or from spread from an

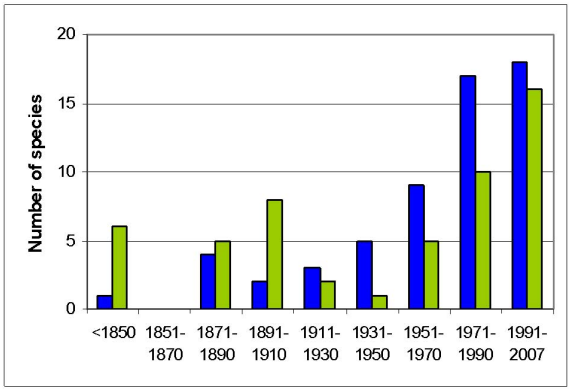


**Figure 1.** Periods of first known Irish records for alien aquatic species occurring in freshwater (green) brackish and marine environments (blue). Note: These may not be the real arrival dates

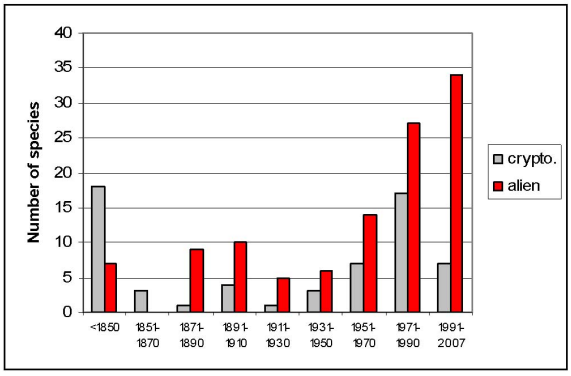


**Figure 2.** Periods for all first known Irish records for alien aquatic species (red) and cryptogenic species (grey). Note: These may not be the real arrival dates

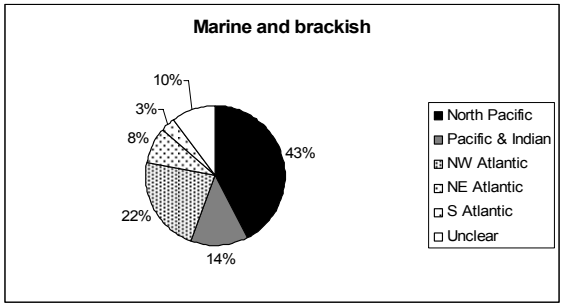


**Figure 3.** Native origin of alien brackish and marine species occurring on Irish coasts

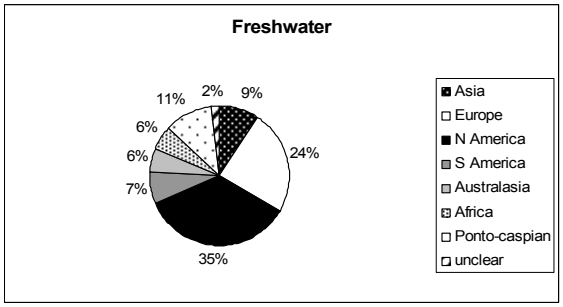


**Figure 4.** Native origin of aquatic species occurring in Irish inland waters

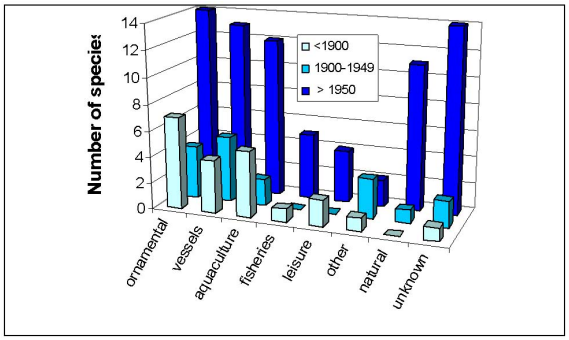


**Figure 5.** The numbers of aquatic alien species introductions associated with human activities over different time periods where there is direct evidence, or where it is likely that a particular human activity is involved in an arrival to Ireland

introduction that took place elsewhere within Europe. All other activities range from less than a quarter to a half of any of these principal modes of transmission. However, there is a large compo-nent of species whose mode of arrival remains unknown. All of the ornamental species will have been released to freshwater environments and the majority of the brackish and marine species will have arrived with shipping or aqua-culture activities.

**Table 1.** Relative distributions of alien species considered to be established in Irish aquatic environments

| Recent Distributions | Freshwater | Brackish/ Marine |
|---|---|---|
| Single locality | 6 | 5 |
| Localities | 16 | 12 |
| Regional | 8 | 3 |
| Widespread | 7 | 11 |

**Table 2.** Status of alien species in Irish aquatic environments. From this list the numbers in cultivation are also indicated

| Population Status | Freshwater | Brackish/ Marine |
|---|---|---|
| Abundant | 6 | 6 |
| Common | 20 | 18 |
| Rare | 11 | 7 |
| No further records/ extinct | 8 | 16 |
| unknown | 8 | 5 |
| *cultivated* | *15* | *7* |

Many of the aliens in both the freshwater and brackish and marine environments have similar patterns for distribution (Table 1) and their status (Table 2).

## Discussion

A-hundred-and-twelve alien species have been recognised as occurring in Ireland, and sixty-three cryptogenic species, up to the end of June 2007. Further species have almost certainly yet to be revealed or reported and it is likely that there will be additions from disparate sources not found in this exercise. The high preponderance of aliens recorded from one or more localities (Table 1) suggests there are future opportunities for these species to expand. The larger numbers of species known to be common or abundant (Table 2 ) may merely reflect findings of species more easily observed while those that are rare and less significant are overlooked. Costello et al. (1996) indicated that there are many more species yet to be described as new to science from British and Irish waters but the numbers will vary according to each taxonomic group and depend on available expertise, their size and distinctiveness.

Islands off continents have a reduced diversity due to the different levels of separation caused by linear distance, strength and direction of water and wind currents and intervening depths. Rare or occasional events that inoculate islands may be important in the establishment and colonisation of islands to form a native biota. However, in recent decades the efficient, diverse and far-ranging extent of transport modes has enabled access to a greater diversity of species from all world regions. Nevertheless many arrivals to islands can be predicted on account of their appearance and spread on nearby landmasses. This provides managers with an advantage by providing an advanced warning of some impacting species.

Some species may be difficult to classify as alien or cryptogenic, as in the case of expansions in the ranges of the plants *Hottonia palustris*, *Stratiotes aloides* and snails *Planorbarius cornuta* and *Viviparus viviparus*. These will be considered by some to have confined 'native' populations but different populations from overseas may have been imported which might explain their recent vigorous spread in the wild. Classifying a species moved from one nearby region in Ireland to another, for example *Groenlandia densa,* is likely to rely on different definitions on the scale of the extended range to different bays or catchments and/or to different administrative/political regions. Consequently the opinions as to the status of a species may vary.

The natterjack toad *Bufo calamita*, according to a Whilde (1993) might have been introduced with sand ballast; and until the recent work by Rowe et al (2006) would have been classified as cryptogenic. Their study of toad populations throughout its European range, using mitochondrial DNA, found the Irish population to be distinct and so considered it to be native to Ireland. Normally an alien species will have a known range that exists outside of Ireland. However, some such as the wasting disease of the eel-grass *Labrynthula zosterae* is almost certainly introduced to Ireland although its origin remains unknown.

Of particular interest to managers are those alien species that are recognised as having some impact. The Irish Environmental Protection Agency (EPA, 2004) and the Environment and Heritage Service of Northern Ireland (Anon, 2005) undertook alien species risk analyses in accordance with Article 5 of the Water Framework Directive (WFD) (EU 2000) (apart from microbiota and parasites). The two agencies listed nine aquatic species present in Ireland of management priority: *Azolla filiculoides, Crassula helmsii* (Figure 6)*, Hydrocotyle ranunculoides, Elodea nuttallii* (Figure 7)*, Myriophyllum aquaticum, Sargassum muticum, Spartina anglica, Dreissena polymorpha* (Figure 8) and *Leuciscus leuciscus*.

**Figure 6.** The ornamental plant *Crassula helmsii* in clay pits on the Ards Peninsula, Northern Ireland, June 2006. Photo: Dan Minchin

**Figure 8.** Settlement of spat of the zebra mussel *Dreissena polymorpha* on an older shell at a time of rapid expansion in Lough Derg, June 1998. Photo: Dan Minchin

**Figure 7.** The ornamental plant *Elodea nuttallii* from Lough Derg, June 2005. Photo: Dan Minchin

**Figure 9.** The ornamental plant *Lagarosiphon major* from Lough Corrib in the west of Ireland. Photo: Dan Minchin

Certainly in Ireland the zebra mussel has had important impacts (Minchin et al. 2006) and is likely to continue to spread over decades (Karatayev et al. 2006). To this list three further aquatic species have become notable since these accounts were assembled, the Chinese mitten crab *Eriocheir sinensis,* the South African pondweed *Lagarosiphon major* (Figure 9) and the colonial tunicate *Didemnum* sp. (Figure 10).

Specimens of the Chinese mitten crab have only recently appeared in the Waterford Estuary on the Irish south coast but it has the potential to expand its range throughout much of Ireland because many of the main river basins are connected by canals (Minchin 2006b). The South African pondweed has become dominant in a large area of one lake (J Caffrey pers. comm.) and there is a risk this species will spread. The origin of the *Didemnum* sp. is unknown and is classed here as being cryptogenic although all indications suggest it is an alien species. This marine tunicate has not yet been fully identified due to the small number of anatomical features, which can be variable. However, its growth and often pendulous appearance is similar to *D. vexillum* described from New Zealand (Kott 2002) and *D. vestum* described from the east coast of North America (Kott 2004) where invasive forms have been noted (Pannell and Coutts 2007; Valentine 2007a, 2007b). There are no previous records to the findings of Minchin and Sides (2006) in Irish waters who between them will have had over fifty years diving experience. It is true that some species are likely to have been recorded many years after an arrival, likely to be the case for *Clymenella*

*torquata*. This annelid was most probably introduced to Ireland during the late 1800s or early 1900s with imports of half-grown North American oyster *C. virginica* for ongrowing. Due to its abundance and form it is very unlikely that the *Didemnum* sp. would have been overlooked in the same way.

There are several diseases and parasites, and some, such as the crayfish plague *Aphanomyces astaci* and the shell disease of oysters *Ostracoblabe implexa*, are no longer thought to remain in Ireland. However, there are two parasites causing significant impact: the haplosporidian *Bonamia ostreae* a blood parasite of the native oyster *Ostrea edulis* and the nematode parasite of eels *Anguillicola crassus* (Figure 11). *B. ostreae* may have originated in California (Elston et al. 1986) arriving with transfers of the European native oyster *Ostrea edulis* to France from where the disease is thought to have spread to Ireland. Although reduced densities and suspended culture result in lower mortalities there have been considerable declines in affected wild fisheries and a change to culturing of the Pacific oyster *Crassostrea gigas* (Héral 1989). The Oriental eel parasite *Anguillicola crassus* arrived with a consignment of the Pacific eel *Anguilla japonica* from Taiwan in an European aquaculture trial. This nematode resides beneath the air bladder feeding on the blood supplied to it (Kennedy and Fitch 1990) and causes damage to other internal organs (Lefebvre et al. 2004) and eels entering the winter have reduced levels of fat (DW Evans pers. comm.) and is likely to result in an inability to regulate their buoyancy and have sufficient reserves for the spawning migration. Unfortunately this species is beyond any control on account of the large number of paratenic hosts that can include aquatic insects (Moravec and Škoríková 1998). Other impacting diseases of fish in Britain such as the rosette-like agent (Gozlan et al. 2005) could gain access to Ireland with aquarium fish imports or releases of sport fishes.

Species likely to be of consequence, and yet to be recorded in Ireland, will be among those already recognised as causing impacts in Britain or northern Europe. Advanced targeting of these may enable eradication or reduction of their spread should they arrive. Early intervention using a regular rapid assessment surveys as developed by Ashton et al (2006) and Minchin (2007b) provides practical information for managers by revealing sites of alien species arrivals and range extensions of species already present.

**Figure 10.** The cryptogenic tunicate *Didemnum* sp. overgrowing mussels and removed from a floating pontoon in the Malahide Estuary on the Irish east coast. June 2006. Photo. Dan Minchin

**Figure 11.** *Anguillicola crassus* a nematode parasite of the European eel, Lough Derg 2006. Photo. Dan Minchin

It has not been possible to determine the human activities responsible for all of the introductions; but almost three-quarters of all known entries involve deliberate and purposeful

trade to Ireland, albeit some of these introductions will have been misguided or associated with traded species. Some will have initially been confined but subsequently became released or escaped. For several species their arrival can not be related to a single human activity. Yet when all of the possible modes of entry are pooled a similar trend emerges (Figure 12). Should there have been fore-knowledge of the nine priority species (under Article 5 of the WFD, see above) eight could have been 'prevented' on the basis of risk assessments; and of the three additional species of concern, one. However, such foresight was acquired only after an introduction was made as in the case of the deliberate plantings of *Spartina anglica* used to accrete land (Cummins 1930) but was later found to result in ecological impacts (McCorry and Otte 2000).

The large number of ornamental plants appearing in new localities in the wild is of concern and there are also several aquarium species, other than plants, on sale that may become introduced to the wild that include freshwater snails, crabs, crayfish, fish (such as sturgeon and pumpkinseed) and terrapins. It is possible that some of these will be found in the wild over the coming decades.

The incomplete knowledge of Ireland's native assemblages and of human species transmissions after the last glacial period makes it difficult to evaluate what is native and what is introduced. For example, the appearance of the soft-shelled clam *Mya arenaria* may have resulted from early Viking exploration from North America during about the 1300s (Strasser 1999), or perhaps from a late and natural northward re-expansion. Similarly the 'shipworm' *Teredo navalis* may have arrived in the hulls of wooden ships, yet drifting tree parts must have been a frequent form of flotsam at a time when there were extensive forests.

On account of the poor knowledge of the mechanisms of natural dispersal many species have been classified as cryptogenic. While some may be spread after an arrival following human activities their subsequent dispersal may occur with different combinations of natural and human spread. Remote appearances are often deduced as being due to human activities but might also be due to the transmission of a specific stage by natural means. Without a better knowledge of natural dispersal mechanisms there will continue to be some confusion on the status of some species. Knowledge of the natural mechanisms of dispersal are important to deduce, not only to classify their status correctly, but because efforts by management spent in control of some aliens may be rendered ineffective because of efficient natural spreading mechanisms.

Birds have the capability of spreading species inadvertently on the body, in the gut or tissues as parasites. Some may equally have arrived with fish introductions, i.e. freshwater fish eye-flukes. The hydroid *Cordylophora caspia* appears in widely separated Irish lagoons frequented by birds that might have transmitted the resting menont stage. However, *C. caspia* is generally considered to be alien in many parts of Europe; but their transmission elsewhere in Europe may also have been with bird movements. The semi-tropical aquatic macrophyte *Hydrilla verticillata*, listed as one of the worlds most invasive species (ISSG 2007), according to Preston et al. (2002) is considered to be native. It occurs in two remote western Irish lakes and may have been carried there with migrating waterfowl. Scannell and Webb (1976) found it produced an abundance of all-female flowers under green-house conditions indicating the plant does not enjoy optimal conditions in Ireland. Invasive plants only known to propagate vegetatively may not be native (i.e. *Hottonia palustris*, *Hydrilla verticillata*, *Stratiotes aloides*), and a species occurring with only one sex present may not be native, an argument used by Cook and Urmi-König (1983). The appearance of the aquatic macrophyte *Ceratophyllum submersum* in lakes or coastal lagoons might also be explained by the presence of wildfowl. Meteorological events may even cause some species to be carried to Ireland. This may have happened with the arrival of the once established insect *Microvelia pygmaea* to Lough Gur in the southern midlands of Ireland (Walton 1985).

Conditions following the last deglaciation will have enabled anadromous and catadromous fishes access to Ireland's river catchments. There is a presumption that those intolerant of marine conditions will all have been introduced. Giraldus Cambrensis on visits to Ireland 1183 and 1185 referred to an absence of several fishes by name such as the pike (Went 1957) and cyprinids as being absent (Moriarty and Fitzmaurice, 2000). Such reported absence has not been considered to be sufficient evidence in this account to include them as aliens unless there are records of an introduction since then. Some fishes might have survived in refugia and

subsequently expanded their range from areas now inundated by the sea (Ménot et al 2006). Yet it is possible that some fishes and a crustacean, the white-clawed crayfish *Austropotomobius pallipes,* were introduced during monastic times to Ireland (Gouin et al. 2003).

Recognised invaders can be prevented entry by using pre-border management measures. Mangers have the capability of controlling deliberate introductions by legislation and by monitoring of imported ornamental products and by applying precautionary measures in relation to aquaculture stock imports that may have associated pests, parasites and diseases (ICES 2005). Yet large bulk transmissions, although inspected, could carrying unwanted introductions as happened with the introduction of associated species with imports of half-grown Pacific oysters from France (Holmes and Minchin 1995; Minchin et al. 1993). Such imports could include cysts contained in shell spaces or in the molluscan gut (Dijkema 1992) or otherwise attach to the shells of oysters (Mineur 2007a). Controls on ships' ballast water are confronted with problems of scale for effective treatment (IMO 2004) and presently mid-ocean exchanges are only suitable in reducing primary inoculations over large distances whereas short sea-going journeys have insufficient time for such an exchange process. Consequently secondary spread by shipping is likely to continue until some practical sterilisation approach is generally employed. Despite any of these measures it is difficult to see how microbal pathogens can be controlled (Drake et al. 2007). The usage of less-effective antifouling paint applications, of lower toxicity, on ship-hull are likely to result in further alien expansions world-wide (Minchin and Gollasch 2003). Hull fouling by ships (Gollasch 2002, Mineur 2007b) continues to be a significant problem and leisure craft also have the capability of inoculating the many bays and inlets that ships do not visit (Floerl 2002, Minchin et al. 2006b). Impacts can be reduced with specific forms of boat harbour design (Floerl and Inglis 2003).

The general changes in weather patterns with warmer over-wintering water temperatures, most probably resulting from an alteration of overall current flow in the north-east Atlantic and in the Polar Sea (Greene and Pershing 2007) allow species with poor lower temperature tolerances to survive and enhance the opportunities for the spread of aliens (Stachowitz et al. 2002). Those requiring higher temperatures for reproduction may now colonise after being introduced. For example the layings of hatchery produced Pacific oysters have over the last decade produced small settling numbers in different Irish bays (Boelens et al. 2005). Vagrants may also establish themselves and the distinction of these from those introduced by human activities is likely to lead to additions to the cryptogenic list for Ireland.

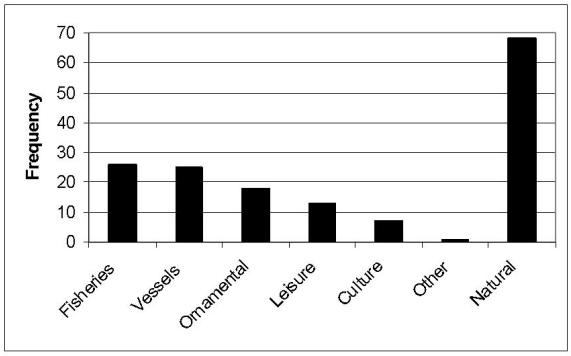


**Figure 12.** Accumulated frequency of possible modes of arrival for an alien species to Ireland

With expansion of the European Union to include eastern European countries further risks of transmissions of alien species arise with the policy of an open market (Howarth and McGillivray 1994). The Ponto-caspian bioprovince has a separate and distinct biota which has already made advances across Europe (Bij de Vaate et al 2002) and small numbers of these will have recently arrived in Ireland, such as the zebra mussel *D. polymorpha,* and its commensals, and the amphipod *Chelicorophium curvispinum*. It is likely that the spread of further species from this region will continue along the inland navigation network (Panov et al. 2007; Galil and Minchin 2006; Minchin et al 2006c). Some of these may be expected to arrive in Ireland as a result of different human activities.

## Conclusion

One-hundred-and-twelve species are considered to be introduced to Ireland of which sixty-eight are considered to be established and sixty-three cryptogenic species have been identified. Many other species have almost certainly yet to be revealed. Fourteen species have been considered to be of high impact and continue to expand their

ranges in Ireland. The high degree of human mobility and the expansion of the European trading block as well as continued trade will result in further species becoming introduced from Britain and Northern Europe. Some pathways pose special risks and management may more effectively apply controls on specific species known to result in ecological and economic impacts that may, for example, be imported as, or with, ornamentals and those involved in aquaculture. With a policy of open trade and expansion of the European Union further species are likely to be inadvertently or deliberately brought to Ireland. More emphatic controls to protect Ireland's aquatic ecosystems are needed if further high impacting species are to be prevented from arriving. Such pre-border management is a cheaper and easier option and will involve a shared responsibility with different user groups.

## Acknowledgements

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**Annex 1**

List of alien species in inland waters, coastal and sea areas of Ireland

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Firmicutes, Bacilli** | | | | | | | | |
| Aerococcaceae | | | | | | | | |
| *Aerococcus viridans* Williams et al. 1953* | | | 1961 | NW Atlantic | with *Homarus americanus* imports | no further records | mortality in lobsters | Gibson 1961 |
| **Oomycota, Oomycetes** | | | | | | | | |
| Saprolegniaceae | | | | | | | | |
| *Aphanomyces astaci* Schikora 1906* | 1987 | | | N America | fishing equipment | no recent records | mortality in *A. pallipes* | Reynolds 1988, Mathews & Reynolds 1992, Lyons & Kelly-Quinn 2003 |
| *Ostracoblabe implexa* Bornet & Fiahault* | | 1951 | 1951 | unknown | oyster imports | extinct | shell blisters on native oysters | Cole & Hancock 1956, CB Duggan pers. comm.. |
| **Labyrinthulomorpha, Labyrinthulomycetes** | | | | | | | | |
| Labyrinthulidae | | | | | | | | |
| *Labyrinthula zosterae* Porter & Muehlstein 1989* | | 1926 | 1926 | unknown | ships ballast water | no recent records | die-off of sea grass, *Zostera marina* | Renouf 1939, Whelan & Cullinane 1987 |
| **Haplosporidia** | | | | | | | | |
| Haplosporididae | | | | | | | | |
| *Bonamia ostreae* Pichot et al. 1980* | | 1988 | 1988 | NE Pacific | aquaculture, shipping | established | native oyster mortalities | McArdle et al. 1991, Culloty & Mulcahy 1996, Culloty et al. 1999, Culloty et al. 2007 |
| **Ciliophora, Ciliatea** | | | | | | | | |
| Ophryoglenidae | | | | | | | | |
| *Ophryoglena hemophaga* Molloy et al. 2005* | 2004 | | | Ponto-caspian | leisure craft hull fouling | established | symbiont of *Dreissena polymorpha* | Burlakova et al. 2006 |
| Conchcophthiridae | | | | | | | | |
| *Conchophthirus acuminatus* Claparède & Lachman* | 2004 | | | Ponto-caspian | leisure craft hull fouling | established | symbiont of *Dreissena polymorpha* | Burlakova et al. 2006 |
| **Dinophyta. Dinophyceae** | | | | | | | | |
| Gymnodiniaceae | | | | | | | | |
| *Karenia mikimotoi* (Miyake et Kominami ex Oda) G Hansen et Ø Moestrup, 2000 | | | 1976 | N Pacific | alongshore drift | established | sporadic blooms, ichthyotoxins ,invertebrate mortalities | Ottway et al, 1979: Pybus 1980, McMahon et al. 1998, Raine et al. 2001 |
| **Ochrophyta, Coscinodiscophyceae** | | | | | | | | |
| Coscinodiscaceae | | | | | | | | |
| *Coscinodiscus wailesii* Gran & Angst 1931 | | | 1979 | Indo-Pacific | alongshore drift | established | bloom forming | Edwards et al. 2001 |
| *Odontella sinensis* (Granville) Grunow 1884 | | | <1997 | N Pacific | alongshore drift | established | bloom forming | McKinney et al. 1997 |
| Skeletonemataceae | 1980 | | | Baltic Sea | unknown | no recent records, probably established | unknown | Gibson et al. 1993 |
| *Skeletonema subsalsum* (A Cleve-Euler) Bethge 1928 | | | | | | | | |
| **Haptophyta, Haptophyceae** | | | | | | | | |
| *Isochrysis* aff. *galbana* 'Tahitian isolate' | | | 1970s | Pacific | aquaculture | unknown | cultured for feeding bivalves | Minchin 2006, B Ottway pers. comm. |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Ochrophyta, Phaeophyceae** | | | | | | | | |
| Scytosiphonaceae | | | | | | | | |
| *Colpomenia peregrina* (Sauvageau) Hamel 1927 | | | 1935 | Pacific | surface drift aquaculture | established | possible competition | Vandermeulen & deWreede 1986, Minchin 1991 |
| Sargassaceae | | | | | | | | |
| *Sargassum muticum* (Yendo) Fensholt 1955 | | | 1995 | N Pacific | aquaculture, drift | established | competition, habitat modification, affecting navigation | Boaden 1995, Loughnane & Stengel 2002, Simkanin 2004 |
| **Rhodophyta, Florideophyceae** | | | | | | | | |
| Bonnemaisoniaceae | | | | | | | | |
| *Bonnemaisonia hamifera* Hariot, 1891 | | | 1911 | N Pacific | unknown | established | competition | Breeman et al 1988, Guiry & Ni Donnachada 2001 |
| Dasyaceae | | | | | | | | |
| *Asparagopsis armata* Harvey 1855 | | | 1939 | Australasia | shipping | established, S & W coasts | cultivated | DeValera 1942, Morrissey et al. 2001, Kraan & Barrington 2005 |
| *Heterosiphonia japonica* Yendo 1920 | | | 2002 | NW Pacific | unknown | established | competition | S Kraan pers. comm |
| Rhodomeliaceae | | | | | | | | |
| *Neosiphonia harveyi* (J Bailey) M-S Kirr, H-G Choi, Guiry & GW Saunders 2001 | | | 1970s | N Pacific | unknown | established | unknown | Maggs & Hommersand 1993 |
| *Polysiphonia subtillissima* Montagne 1940 | | | 2006 | West Indies | unknown | one locality established | unknown | C. Maggs, pers. comm. |
| Ceramiaceae | | | | | | | | |
| *Antithamnionella spirographidis* (Schiffner) Wollaston 1968 | | | 1973 | N Pacific | shipping, leisure craft or aquaculture | rare, established | unknown | Pybus 1977 |
| Halymeniaceae | | | | | | | | |
| *Cryptonema hibernica* Guiry & L Irvine 1974 | | | 1971 | S Atlantic? | shipping | local, established | unknown | Cullinane & Whelan 1981 ; Cullinane et al. 1984 |
| **Chlorophyta, Bryopsidophyta** | | | | | | | | |
| Codiaceae | | | | | | | | |
| *Codium fragile tomentosoides* (van Goor) Silva, 1955 | | | 1950 | N Pacific | unknown | established | competition | Parkes 1975, Trowbridge 1998 |
| *Codium fragile atlanticum* (Cotton) P Sinva 1955 | | | 1808 | NW Pacific ? | unknown | established | competition | Parkes 1975 |
| **Chlorophyta, Ulvophyceae** | | | | | | | | |
| Ulvaceae | | | | | | | | |
| *Ulva californica* Wille1889 | | <2007 | | E Pacific | vessels | local | unknown | C A Maggs pers. comm. |
| **Pteridiophyta, Filicopsida** | | | | | | | | |
| Azollaceae | | | | | | | | |
| *Azolla filiculoides* Lam. | 1893 | | | West N & S America | ornamental | locally abundant, established | dense surface growths, deoxygen-ation of water column | Reynolds 2002 |
| **Magnoliophyta, Liliopsida** | | | | | | | | |
| Pontederiaceae | | | | | | | | |
| *Pontederia cordata* L. | 1958 | | | N America E | ornamental | one locality, established | unknown | Reynolds 2002 |
| Alismataceae | | | | | | | | |
| *Sagittaria rigida* Pursh. | 1999 | | | N America E | ornamental | local, established | unknown | Reynolds 2002 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| Poacaeae | | | | | | | | |
| *Spartina anglica* CE Hubb | | 1925 | 1925 | N Europe | habitat management | established | competition, accumulation of sediments | Curtis & Sheehy-Skeffington 1998, Hammond & Cooper 2002, Reynolds 2002 |
| *Spartina pectinata* Link | ~1910 | | | N. America | ornamental | one locality, established | unknown | Scannell & Jebb 2000 |
| *Spartina x townsendii H & J Groves* Roman | | 1933 | | hybrid | habitat management | rare, declining | unknown | Reynolds 2002 |
| Acoridae | | | | | | | | |
| *Acorus calamus* Linnaeus 1753 | 1744 | | | N.AmericaN Asia | ornamental | local and widespread | unknown | Reynolds 2002 |
| Aponogetonaceae | | | | | | | | |
| *Aponogeton distachyos* L.f. | 1900s | | | S Africa | ornamental | one locality | unknown | Reynolds 2002 |
| Hydrocharitaceae | | | | | | | | |
| *Egeria densa* Planch. | 1988 | | | S America | ornamental | rare | unknown | Reynolds 2002 |
| *Elodea canadensis* Michx. | ~1836 | | | N America | ornamental | widespread, established | competition | Reynolds 2002 |
| *Elodea nuttallii* (Planch.) H St John | 1984 | | | N America | ornamental, aquaria | locally abundant established expanding | competition, affecting navigation | Simpson 1985, Minchin & Boelens 2007 |
| *Lagarosiphon major* (Ridley) Moss | 1966 | | | S Africa | ornamental, fishing | locally abundant, established expanding | dense growth, affecting navigation, competition | Cotton & Caffrey 2000, Reynolds 2002 |
| Juncaceae | | | | | | | | |
| *Juncus planifolius* R. Br | 1971 | | | Australasia, S America | unknown | locally established | unknown | Reynolds 2002 |
| Araceae | | | | | | | | |
| *Lemna minuta* Kunth | 1993 | | | Americas | ornamental | widespread, established, expanding | local competition, affects abstraction | Cotton 1999, Lucey 2003, Preston & Croft 1997 |
| *Lysichiton americanus* Hultén & St John | ~1930 | | | N America | ornamental | locally common, established | unknown | O' Malley 1996, Reynolds 2002 |
| **Magnoliophyta, Magnoliopsida** | | | | | | | | |
| Primulaceae | | | | | | | | |
| *Hottonia palustris* L. | 1898? | | | Europe | ornamental | locally abundant, established expanding | competition, affecting navigation | Minchin & Boelens 2005, 2007 |
| Apiaceae | | | | | | | | |
| *Hydrocotyle ranunculoides* L. f. | 2002 | | | N America | ornamental, aquaria | locally established | competition | Day 2004 |
| Haloragaceae | | | | | | | | |
| *Myriophyllum aquaticum* (Velloso) Verdc. | 1990 | | | S America | ornamental, water purification | locally abundant, established | competition, surface growths | Reynolds 2002 |
| Nymphaeaceae | | | | | | | | |
| *Nuphar pumila* (Timm.) DC | 1898 | | | Europe, N Asia | ornamental | local, established | competition | Reynolds 2002 |
| Menyanthaceae | | | | | | | | |
| *Nymphoides peltata* (S.G. Gmel.) Kuntze | 1850 | | | Europe | ornamental | local, established | competition | Reynolds 2002 |
| Crassulacea | | | | | | | | |
| *Crassula helmsii* (Kirk) Cockayne | 1985 | | | Australasia | ornamental | locally abundant, established | dense surface growths | Weyl & Hackney 1988, Day 2004 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Cnidaria, Anthozoa** | | | | | | | | |
| Diadumenidae | | | | | | | | |
| *Diadumene lineata* (Verrill 1869) | | 1974 | 1974 | NW Pacific | aquaculture hull fouling | local | unknown | Ryland & Nelson-Smith 1975 |
| **Nematoda, Dracunculoidea** | | | | | | | | |
| Anguillicolidae | | | | | | | | |
| *Anguillicola crassus* Kuwahara, Niimi & Itagaki 1974* | 1998 | | | E Asia | eel transport shipping | widespread, established | endoparasite of *Anguilla anguilla* | Kennedy & Fitch 1990, Evans & Mathews 1999, Kirk 2003 |
| **Platyhelminthes, Trematoda** | | | | | | | | |
| Pseudodactylogyridae | | | | | | | | |
| *Pseudodactylogyrus anguillae* (Yin & Sprosten 1948)* | 1988 | | | Asia | eel transport | present | ectoparasite of *A. anguilla* | McCarthy & Rita 1991 |
| *Pseudodactylogyrus bini* (Kikuchi 1929)* | 1996 | | | Asia | unknown | present | ectoparasite of *A. anguilla* | Copley & McCarthy 2001 |
| Dactylogyridae | | | | | | | | |
| *Dactylogyrus vastator* (Nybelin 1924)* | 1960s | | | Europe | leisure | no recent record | unknown | Kennedy 1993 |
| Dugesiidae | | | | | | | | |
| *Dugesia tigrina* (Girard) | 2001 | | | N America | ornamental | local | unknown | Anderson 2003a |
| **Annelida, Hirudinea** | | | | | | | | |
| Hirudinidae | | | | | | | | |
| *Hirudo medicinalis* Linnaeus 1758 | <1900 | | | Europe | medical treatment | extinct | none | McCarthy 1986 |
| **Annelida, Polychaeta** | | | | | | | | |
| Serpulidae | | | | | | | | |
| *Ficopomatus enigmaticus* (Fauvel 1923) | | 1971 | 1971 | Indo-Pacific | hull fouling | locally abundant established | fouling organism | Kilty & Guiry 1973 |
| Maldanidae | | | | | | | | |
| *Clymenella torquata* (Leidy, 1855) | | | 2006* | NW Atlantic | aquaculture | established | unknown | T Mackie pers. comm. |
| Terebellidae | | | | | | | | |
| *Terebella lapidaria* (Linnaeus 1767) | | | 1993 | continental Europe | aquaculture | no recent record | unknown | Minchin et al. 1993 |
| **Annelida, Clitellata** | | | | | | | | |
| Tubificidae | | | | | | | | |
| *Potamothrix moldaviensis* Vejdovsky & Mrázek 1903 | 2002 | | | Ponto-caspian | unknown, ?ships | probably established | unknown | Sweeney et al. 2003, Sweeney in press |
| *Potamothrix vejdovskyi* (Hrabe 1941) | 2002 | | | Ponto-caspian | unknown, ?ships | probably established | unknown | Sweeney et al. 2003, Sweeney in press |
| *Branchiura sowerbyi* Beddard 1892 | 1909 | | | Asia | ornamental | no recent record | unknown | McCarthy 1974 |
| **Mollusca: Gastropoda** | | | | | | | | |
| Pseudococcidae | | | | | | | | |
| *Ferrisia wautieri* Mirolli 1960 | 2006 | | | N Africa | ornamental | established | unknown | Moorkens 2007 |
| Hydrobiidae | | | | | | | | |
| *Potamopyrgus antipodarum* (JE Gray 1843) | <1900 | <1900 | | Australasia | shipping | widespread & abundant, established | competition | Massey 1903 |
| Physidae | | | | | | | | |
| *Physella acuta* Draparnaud 1805 | 1909 | | | N America | ornamental | established | unknown | Anderson 2003b |
| *Physella gyrina* (Say 1816) | 1995 | | | N America | ornamental | established | unknown | Anderson 1996, 2001, 2004 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| Calyptraeidae | | | | | | | | |
| *Crepidula fornicata* (Linnaeus 1758) | | 1902 | 1902 | NW Atlantic | aquaculture | no known population, individuals | none | Sykes 1905, Spicer 1923, Arnold 1960, Minchin et al. 1995 |
| *Calyptraea chinensis* Linnaeus 1758 | | | 1962 | Europe | fisheries | established spreading | unknown | Minchin et al. 1987, Minchin & Nunn 2006 |
| Haliotidae | | | | | | | | |
| *Haliotis discus hannai* Ino 1953 | | | 1985 | NW Pacific | aquaculture | hatchery production | cultivated | Minchin 1996 |
| *Haliotis tuberculata* Linnaeus 1758 | | | 1978 | Continental W Europe | aquaculture | hatchery production | cultivated | Mgaya & Mercer 1994 |
| **Mollusca : Bivalvia** | | | | | | | | |
| Teredinidae | | | | | | | | |
| *Bankia fimbriata* (Moll & Roch 1931) | | | <1847 | circum-tropical | ship's hull | not established, individual | none | Nichols 1900 |
| Mytilida | | | | | | | | |
| *Brachidontes exustus* Linnaeus 1758 | | | 1977 | W Atlantic | flotsam (metal bouy) | not established, individuals | none | O'Riordan & Holmes 1978 |
| Isognomonidae | | | | | | | | |
| *Isognomon radiata* Antón 1839 | | | 1996 | W Atlantic | flotsam (brush) | not established, individual | none | Minchin pers. ob. |
| Ostreidae | | | | | | | | |
| *Ostrea equestris* Say 1834 | | | 1995 | W Atlantic | flotsam (float) | not established, individuals | none | Minchin pers. ob. |
| *Crassostrea angulata* (Lamarck 1819) ‡ | | 1877 | 1877 | W Europe, + *C. gigas* | aquaculture | not established | none, once cultivated | Wilkins 1989 |
| *Crassostrea gigas* (Thunberg 1793) | | 1969 | 1969 | N Pacific | aquaculture | some recruitment | widely cultivated | De Grave et al. 1998 |
| *Crassostrea virginica* (Gmelin 1791) | | 1875 | 1875 | NW Atlantic | aquaculture | no longer present | none, once cultivated | Minchin et al. 1995 |
| *Dendrostrea frons* (Linneaus 1758) | | | 1983 | W Atlantic | flotsam (float) | not established, individuals | none | West & O'Riordan 1984 |
| Chamidae | | | | | | | | |
| *Chama* sp. | | | 1989 | W Atlantic | flotsam (rope) | not established, individuals | individuals | P Casburn pers. comm. |
| Dreissenidae | | | | | | | | |
| *Dreissena polymorpha* (Pallas 1771) | 1993 | 1993 | | Ponto-caspian | fouling on leisure craft | abundant, established, expanding | competitor, blockages to abstraction piping, fouling organism | Pollox et al. 2003, Juhel et al 2003, Astanei et al 2005, Maguire & Gibson 2005, Minchin et al. 2002, 2006d |
| Pectinidae | | | | | | | | |
| *Patinopecten yessoensis* Jay 1857 | | | 1988 | NW Pacific | aquaculture | no longer present | once cultivated | Minchin & Rosenthal 2002 |
| Veneridae | | | | | | | | |
| *Mercenaria mercenaria* (Linnaeus 1758) | | | 1969 | NW Atlantic | aquaculture | no known populations | once cultivated | Gibson 1970 |
| *Venerupis philippinarum* (Adams & Reeve 1850) | | | 1973 | Pacific | aquaculture | hatchery production | cultivated | Partridge 1977 |
| **Arthropoda, Maxillopoda, Copepoda** | | | | | | | | |
| Myicolidae | | | | | | | | |
| *Myicola ostreae* Hoshina & Sugiura 1953* | | 1993 | 1993 | NW Pacific | oyster movements | local, no recent records | symbiont, no known impact | Holmes & Minchin 1995a |
| Mytilicolidae | | | | | | | | |
| *Mytilicola orientalis* Mori 1935* | | 1993 | 1993 | NW Pacific | oyster movements | local population | endoparasite of *C. gigas* | Grizel 1985, Minchin 2004 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Arthropoda: Maxillopoda, Cirripedia** | | | | | | | | |
| Archeobalinidae | | | | | | | | |
| *Elminius modestus* Darwin 1854 | | 1957 | 1957 | S Pacific | hull fouling | abundant established | competition, fouling organism | Beard 1957, McGrath & King 1992, O'Riordan 1996 |
| Balanidae | | | | | | | | |
| *Balanus amphitrite* Darwin 1854 | | | 1966 | circum-tropical | hull fouling | not-established | fouling organism | Minchin 2000 |
| *Balanus improvisus* Darwin 1854 | | <1950 | | S America | hull fouling | locally abundant, established | fouling organism | O'Sullivan 1983, Minchin 2004 |
| *Megabalanus tintinnabulum* (Linneaus 1758) | | | <1900 | Sub-tropical cosmopolitan | hull fouling | Individual records, not established | fouling organism | O'Riordan 1967 |
| **Arthropoda, Malacostraca, Amphipoda** | | | | | | | | |
| Caprellidae | | | | | | | | |
| *Caprella mutica* Schurin 1935 | | | 2003 | NW Pacific | hull fouling | locally abundant, established | fouling organism | Tierney et al. 2004, Minchin & Holmes 2007 |
| Corophiidae | | | | | | | | |
| *Chelicorophium curvispinum* (Sars 1895) | 2000 | | | Ponto-caspian | unknown | established | unknown | Lucey et al. 2004 |
| Crangonyctidae | | | | | | | | |
| *Crangonyx pseudogracilis* Bousfield 1958 | 1969 | | | N America | ornamental | established | competition | O'Connor et al. 1991 |
| Gammaridae | | | | | | | | |
| *Gammarus pulex* (Linnaeus 1758) | 1958 | | | Europe | stocked from Britain | established | competition | Kelly & Dick 2005 |
| *Gammarus tigrinus* Sexton 1939 | 1931 | | | N America | vessels | established | competition | Costello 1993 |
| **Arthropoda, Malacostraca, Decapoda** | | | | | | | | |
| Grapsidae | | | | | | | | |
| *Eriochier sinensis* (H Milne-Edwards 1853) | | 2006 | 2006 | E Asia | shipping ? | individuals present | unknown | Minchin 2006b |
| Geryonidae | | | | | | | | |
| *Pilumnoides inglei* Guinot & MacPherson 1987 | | | <1900 | E Pacific | hull fouling | individuals, no recent records | unknown | Ingle 1980 |
| Penaeidae | | | | | | | | |
| *Marsupenaeus japonicus* (Bate 1888) | | | 2007 | Indo-Pacific | aquaculture escape | individuals, not thought to be established | unknown | D Quigley pers. comm.. |
| Homaridae | | | | | | | | |
| *Homarus americanus* Herrick 1895 | | | 1961 | NW Atlantic | live food trade | not considered to be established | possible hybridisation | Gibson 1961 |
| **Arthropoda, Insecta, Diptera** | | | | | | | | |
| Chinonomidae | | | | | | | | |
| *Telmatogeton japonicus* Tokunaga 1933 | | 1999 | 1999 | N Pacific | unknown | no more recent records | unknown | Murray 2000 |
| **Chordata, Ascidiacea** | | | | | | | | |
| Botryllidae | | | | | | | | |
| *Botrylloides violaceus* Oka 1927 | | | 2006 | NW Pacific | shipping | locally established | fouling organism | Minchin 2007 |
| Corellidae | | | | | | | | |
| *Corella eumyota* Traustedt 1882 | | | 2005 | circum sub-Antarctic | shipping | locally established | fouling organism | Minchin 2007 |
| Molgulidae | | | | | | | | |
| *Molgula manhattensis* (De Kay 1843) † | | | 1998 | NW Atlantic | unknown | present, may be more frequent | fouling organism | Holmes & Gotto 2000 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| Styelidae | | | | | | | | |
| *Styela clava* Herdman 1882 | | 1971 | 1971 | NW Pacific | shipping aquaculture | locally established | fouling organism | Guiry & Guiry 1973, Parker et al 1999, Minchin et al. 2006a, Minchin 2007 |
| **Chordata : Pisces** | | | | | | | | |
| Salmonidae | | | | | | | | |
| *Oncorhynchus gorbuscha* (Walbaum 1792) | | | 1973 | N Pacific | vagrant from stocking | individuals, not present | none | Went 1974 |
| *Oncorhynchus mykiss* (Walbaum 1792) | 1899 | 1899 | 1899 | NE Pacific | aquaculture | local populations, hatchery production | cultivated | Moriarty & Fitzmaurice 2002 |
| *Hucho hucho* (Linnaeus 1758) | 1993 | | | Europe | unapproved stocking | extinct | unknown | Lucy & Nolan 1996 |
| Clupeidae | | | | | | | | |
| *Alosa sapidissima* (Wilson 1811) | 1900 | | | N America | stocking attempt | extinct | none | Scharff 1900 |
| Ictaluridae | | | | | | | | |
| *Ictalurus catus* (Linnaeus 1758) | 1889 | | | N America | ornamental | no recent record | none | Holmes pers. comm. |
| *Ameiurus melas* (Rafinesque 1820) | 2001 | | | N America | ornamental | no recent record | none | www.fishbase.org |
| Cyprinidae | | | | | | | | |
| *Cyprinus carpio* Linnaeus 1758 | 1634 | | | Asia | stocked ponds | local populations | unknown | Went 1950, Moriarty & Fitzmaurice 2002 |
| *Leuciscus leuciscus* (Linnaeus 1758) | 1889 | | | Europe | live angling bait | established | competitor | Healy 1956 |
| *Rutilus rutilus* (Linnaeus 1758) | 1889 | | | Europe | angling bait | established | competition | Healy 1956, McCarthy 1981 |
| *Leuciscus cephalus* (Linnaeus 1758) | 2004 | | | Europe | unapproved stocking | present, may be established | competition | J Caffrey pers. comm. |
| *Tinca tinca* | ~1634 | | | Europe | stocked ponds | widely distributed | unknown | Went 1950, Moriarty & Fitzmaurice 2002; |
| Characidae | | | | | | | | |
| *Serrasalmis* sp. | 1988 | | | S America | human food discard? | not established | none | P Boaden pers comm.. |
| **Chordata, Mammalia** | | | | | | | | |
| Cricetidae | | | | | | | | |
| *Ondatra zibethica* (Linnaeus 1766 ) | 1929 | | | N America | fur-farm escape | trapped to extinction | none | Fairley 1982, 2001 |

Notes: * diseases, parasites or commensals; † difficult to separate from *M. socialis;* ‡ now considered to be *C. gigas*

**Annex 2**

List of cryptogenic species occuring in inland waters, coastal and sea areas of Ireland. Early dates are suggested for arrivals of vertebrates or their parasites

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Pyrrophyta, Dinophyceae** | | | | | | | | |
| Goniodonatidaceae | | | | | | | | |
| *Alexandrium tamarense* (Lebour) Balech 1985 | | | 1986 | World-wide | oysters, shipping, native | established, local | sporadic blooms | Tylor et al. 1995, Minchin 2004 |
| **Ochrophyta, Raphidophyceae** | | | | | | | | |
| Chattonellaceae | | | | | | | | |
| *Heterosigma akashiwo* (Y Hada) Y Hada ex Y Hare & M Chihara 1967 | | | 1970 | Pacific? | aquaculture shipping | established | sporadic blooms, cultured fish kills | T. McMahon pers. comm.. |
| **Rhodophyta, Rhodophyceae** | | | | | | | | |
| Ceramiaceae | | | | | | | | |
| *Antithamnion densum* (Suhr) MA Howe 1914 | | | 1991 | Indo-Pacific? | unknown | rare, no recent record | unknown | Wallentinus 2002 |
| *Antithamnionella ternifolia* (JD Hooker & Harvey) Lyle 1922 | | | 1930 | Europe | unknown | widespread, established | unknown | Pybus 1977 |
| Gigartinaceae | | | | | | | | |
| *Iridaea* sp. | | | 1972 | Pacific | unknown | rare | single record | Cullinane & Whelan 1984 |
| Gracilariaceae | | | | | | | | |
| *Gracilaria multipartata* (Clemente y Rubio) Harvey 1846 | | | 1977 | | unknown, drift | local, no recent record | unknown | Cullinane & Whelan 1984 |
| **Magnoliophyta, Liliopsida** | | | | | | | | |
| Potamogetonaceae | | | | | | | | |
| *Groenlandia densa* (L.) Fourr | 1866 | | | Europe | turf barges | Established, spread within Ireland | unknown | Dromey 1991, Wyse-Jackson 1988 |
| Hydrocharitaceae | | | | | | | | |
| *Hydrilla verticillata* (L.f.) Royle | 1935 | | | S Africa? | ornamental | local | unknown | Roden 2005 |
| *Stratiotes aloides* L. | 1750 | | | Europe, W Asia | original introduction unknown, ornamental | established, spreading | unknown | Forbes 2000 |
| Alismataceae | | | | | | | | |
| *Luronium latans* (L.) Rafn. | 1900 | | | Europe, N Africa | unknown | local | unknown | Rich et al. 1995 |
| Juncaceae | | | | | | | | |
| *Juncus compressus* Kit. | 1968 | | | Europe, N America | leisure (anglers footwear) | local | unknown | Reynolds 2002 |
| **Magnoliophyta, Magnoliopsida** | | | | | | | | |
| Ceratophyllaceae | | | | | | | | |
| *Ceratophyllum submersum* L. | 1989 | 1989 | | Europe | ornamental, birds | local, spreading | fouling | Smith & Wolfe-Murphy 1991, McNeill 2003, Reynolds 2006 |
| **Cnidaria, Hydrozoa** | | | | | | | | |
| Clavidae | | | | | | | | |
| *Cordylophora caspia* (Pallas 1771) | 1979 | 1979 | | Ponto-caspian | vessels birds | local | unknown | Healy et al. 1982 |
| **Acanthocephala, Palaecanthocephala** | | | | | | | | |
| Pomphorynchidae | | | | | | | | |
| *Pomphorhynchus laevis* Muller 1776* | ~1700 ? | | | Europe | fisheries | local established | fish parasite | Kennedy et al. 1989, O'Mahony et al. 2004 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| Echinorhynchidae | | | | | | | | |
| *Acanthocephalus anguillae* (Müller 1790)* | ~1700 ? | | | Europe | stocking | local, established | fish parasite | Black 1978, Kennedy et al. 1989 |
| *Acanthocephalus lucii* (Müller 1776)* | ~1700 ? | | | Europe | stocking | established | fish parasite | Holland & Kennedy, 1997 |
| **Plathelminthes, Trematoda** | | | | | | | | |
| Diplostomatidae | | | | | | | | |
| *Posthodiplostomum cuticola* (Nordmann 1832)* | <1960s | | | Europe | fisheries, birds | established | fish parasite | Holland & Kennedy 2003 |
| *Tetracotyle percafluviatilis* (Linstow 1856)* | ~1700s | | | Europe | fisheries birds | no recent record | fish parasite | Holland & Kennedy 1998 |
| *Tylodelphys clavata* (Nordmann 1832)* | 1980s | | | Europe | fisheries, birds | established | fish parasite | McLoughlin & Irwin 1991 |
| *Tylodelphys podicipina* (Kozicka & Niewiadomska 1960)* | 1990 | | | Europe | Fisheries, birds | local, no recent record | fish parasite | El-Toumi & McCarthy 1990 |
| Discocotylidae | | | | | | | | |
| *Diplozoon paradoxum* von Nordman 1832* | 1950s | | | Europe | leisure, fisheries | unknown | fish parasite | Stranock 1979, Holland & Kennedy 1998 |
| Dendrocoelidae | | | | | | | | |
| *Bdellocephala punctata* (Pallas 1774)* | 1972 | | | Europe | unknown | no recent records | fish parasite | McCarthy 1973 |
| Caryophyllaeidae | | | | | | | | |
| *Caryophyllaeides fennica* (Schneider 1902)* | ~1700? | | | Europe | fisheries, leisure | local, unknown | fish parasite | Kennedy 1966 |
| *Caryophyllaeus laticeps* (Pallas 1781)* | ~1700? | | | Europe | fisheries, leisure | local, unknown | fish parasite | Holland & Kennedy 1998 |
| Diphyllobothriidae | | | | | | | | |
| *Ligula intestinalis* (Linneaus 1758)* | ~1973 | | | Europe | leisure, birds | widespread, established | fish parasite | Bean & Winfield 1989 |
| **Platyhelminthes, Cestoda** | | | | | | | | |
| Diphyllobothridae | | | | | | | | |
| *Diphyllobothrium latum* (Linnaeus 1758)* | <1945 | | | Europe | leisure fisheries birds | local | fish parasite | Holland & Kennedy 1998 |
| **Annelida** | | | | | | | | |
| Hirudinidae | | | | | | | | |
| *Erpobdella testacea* (Savigny 1820) | 1900s | | | Europe | unknown | local, established | unknown | McCarthy 2002 |
| Serpulidae | | | | | | | | |
| *Paralaeospira malardi* Caullery & Mesnil 1897 | | | <1977 | S. hemisphere? | vessels | local, no recent record | unknown | Knight-Jones & Knight-Jones 1977 |
| Spirorbidae | | | | | | | | |
| *Pileolaria militaris* Claparède 1868 | | | <1977 | warm and tropical seas | vessels | local, no recent record | unknown | Knight-Jones & Knight-Jones 1977 |
| **Mollusca: Gastropoda** | | | | | | | | |
| Planorbidae | | | | | | | | |
| *Planorbarius cornuta* (Linnaeus 1758) | 1895 | | | Europe | ornamental | established | unknown | Anderson 1977, 1983 |
| Viviparidae | | | | | | | | |
| *Viviparus viviparus* (Linnaeus 1758) | 1990s | | | Europe | leisure, ornamental | established, local | unknown | McMillan & Zeissler 1990, Cotton INJ, Minchin et al. 1998 |
| **Mollusca: Bivalvia** | | | | | | | | |
| Myidae | | | | | | | | |
| *Mya arenaria* (Linnaeus 1758) | | <1900 | <1900 | N. America | live food, vessels, larval drift | widespread established | unknown | Ryan 1993 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| Pholadidae | | | | | | | | |
| *Martesia striata* (Linnaeus 1758) | | | 1871 | circum-tropical | in timber | not established | none | J Nunn pers.com. |
| Teredinidae | | | | | | | | |
| *Teredo navalis* Linnaeus 1758 | | 1845 | 1845 | SE Asia? | vessels | probably established, no recent records | damaging timber piles | Minchin 2004 |
| **Arthropoda: Amphipoda** | | | | | | | | |
| Corophiidae | | | | | | | | |
| *Monocorophium sextonae* Crawford 1937 | | | 1982 | S. hemisphere? | vessels | widespread, established | competition | Costello 1993 |
| *Monocorophium insidiosum* Crawford 1937 | 2002 | 2002 | | N Atlantic | unknown | local | unknown | Oliver et al 2007 |
| *Corophium multisetosum* Stock 1952 | 1993 | | | Europe | vessels | local, established | unknown | De Grave & Wilkins 1994 |
| **Arthropoda: Copepoda** | | | | | | | | |
| Caligidae | | | | | | | | |
| *Caligus pageti* Russel 1925* | | | 1986 | Mediterranean | vessels | local, may be established | unknown, | Holmes 1998 |
| Mytilicolidae | | | | | | | | |
| *Mytilicola intestinalis* Steuer 1902* | | | 1948 | Mediterranean | vessels, aquaculture | local, established | gut parasite of mussels | Grainger 1951, Crowley 1972, Murray 1972 |
| Sabelliphilidae | | | | | | | | |
| *Herrmannella duggani* Holmes & Minchin 1991* | | | 1982 | unknown | vessels, aquaculture | South and west coasts, no recent records | may damage oyster *Ostrea edulis* gills | Holmes & Minchin 1991 |
| Lichomolgidae | | | | | | | | |
| *Critomolgus actinae* D.V.* | | | 1973 | Europe | vessels | established | unknown | Briggs 1973 |
| Cyclopinidae | | | | | | | | |
| *Muceddina multispinosa* Jaume & Boxshall 1996 | | | 1982 | Mediterranean, eastern Atlantic islands | vessels | rare, no recent record | unknown | Holmes & Gotto 2000 |
| Taeniacanthidae | | | | | | | | |
| *Taeniastrotos sp.** | | | 1993 | Indo-Pacific? | vessels | local, no recent record | unknown | Holmes & Minchin 1985b |
| Ergasilidae | | | | | | | | |
| *Ergasilus gibbus* (Nordmann 1832)* | 1969 | | | Europe | leisure, fisheries | local established | unknown | Kennedy 1993 |
| Porcellidiidae | | | | | | | | |
| *Porcellidum ovatum* Haller 1879 | | | 1991 | Pacific? | vessels, aquaculture | established, local | unknown | Holmes 1991 |
| Laophontidae | | | | | | | | |
| *Heterolaophonte hamondi* Hicks 1975 | | | 1986 | unknown | vessels | no recent record | unknown | Murphy & Holmes 1990 |
| **Arthropoda: Isopoda** | | | | | | | | |
| Limnoriidae | | | | | | | | |
| *Limnoria quadripunctata* (Holthuis 1949 | | | 1995 | unknown | vessels, drift wood | no recent record | unknown | Holmes 1996 |
| **Arthropoda: Cirripedia** | | | | | | | | |
| Scalpellidae | | | | | | | | |
| *Pollicipes pollicipes* (Gmelin 1769) | | | 1900 | E N Atlantic | vessels | individuals, no recent record | unknown | Thompson 1856 |
| **Arthropoda: Decapoda** | | | | | | | | |
| Astacidae | | | | | | | | |
| *Austropotamobius pallipes* (Lereboullet 1858) | 1100s? | | | W Europe | fisheries, stocking | established, widespread | not studied | Reynolds 1997, Holdich et al. 1999, Gouin et al 2003 |
| **Arthropoda: Cladocera** | | | | | | | | |
| Daphniidae | | | | | | | | |
| *Daphnia atkinsoni* Baird 1859 | 1970 | | | Europe | ornamental, birds | no recent record | unknown | Fryer 1985 |

| Species | Year of first record and recipient zone | | | Native origin | Known or likely spread | Current status | Impact in Ireland | References |
|---|---|---|---|---|---|---|---|---|
| | Fresh waters <1psu | Brackish waters 1-30psu | Marine waters >30psu | | | | | |
| **Bryozoa, Phylactolaemata** | | | | | | | | |
| Lophopodidae | | | | | | | | |
| *Lophopus crystallinus* (Pallas 1768) | 1856 | | | Europe | ornamental | no recent record | unknown | Smith 1994 |
| **Chordata: Ascidiacea** | | | | | | | | |
| Didemnidae | | | | | | | | |
| *Didemnum sp.* | | | 2005 | unknown | vessels | established two localities | overgrows benthos | Minchin & Sides 2006 |
| Ascidiidae | | | | | | | | |
| *Phallusia mamillata* (Cuvier 1815) | | | <1979 | Europe | vessels | one bay established | unknown | Minchin 2000 |
| **Chordata: Pisces** | | | | | | | | |
| Cyprinidae | | | | | | | | |
| *Abramis brama* (Linnaeus 1758) | 1600s | | | Europe | fisheries | established | hybridises | Moriarty 1982, Hayden 2002 |
| *Gobio gobio* (Linnaeus 1758) | 1600s | | | Europe | unknown | established | unknown | Hayden 2002 |
| *Phoxinus phoxinus* (Linnaeus 1758) | 1600s | | | Europe | ornamental | established | unknown | Hayden 2002 |
| *Scardinus erythrophthalmus* (Linnaeus 1758) | 1600s | | | Europe | fisheries | established | hybridises | Went 1950 |
| Esociidae | | | | | | | | |
| *Esox lucius* Linnaeus 1758 | <1682 | | | Europe | fisheries | widely distributed | predator | Went 1957 |
| Cobitidae | | | | | | | | |
| *Barbatula barbatula* (Linnaeus 1758) | 1600s | | | Europe | ornamental | established | unknown | Hayden 2002 |
| Percidae | | | | | | | | |
| *Perca fluviatilis* Linnaeus 1758 | 1600s | | | Europe | fisheries | established | competitor | Hayden 2002 |
| Gasterosteidae | | | | | | | | |
| *Pungitius pungitius* Linnaeus 1758 | 1856 | | | Europe | unknown, ornamental | established | unknown | Hayden 2002 |
| **Chordata, Amphibia** | | | | | | | | |
| Ranidae | | | | | | | | |
| *Rana temporaria* Linnaeus 1758 | 1700s | | | Europe | unknown, ornamental | established | unknown | Hayden 2002, Marnell 1998 |
| Salamandridae | | | | | | | | |
| *Triturus vulgaris* (Linnaeus 1758) | not known | | | Europe | ornamental | established, local | unknown | Hayden 2002, Marnell 1999 |

NOTES: * parasites and commensals