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Review

Alien species in British brackish and marine waters

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Abstract

Ninety alien species have been identified from British marine and brackish environments; of which 58 are established. Their arrival has been principally due to shipping and imported consignments of cultured species. The majority of alien species were initially reported from the English Channel, with many subsequently spreading northwards to the North or Celtic Seas. The majority of aliens in Britain originate from the North Pacific (N=35), followed by the North-west Atlantic (N=22). Additional alien species may be expected as a result of continued trade, port, and marina developments. Alterations in climate and extreme weather events are likely to result in future changes to the distribution of marine and brackish water alien species around the British coast.

Key words: Celtic seas; English Channel; North Sea; introduction; non-native; invasive; vectors; secondary spread

Introduction

Intentional or unintentional introductions of species (often referred to as non-indigenous, non-native, invasive, exotic, or alien) by humans to regions outside their native ranges has been on-going for thousands of years (Carlton and Geller 1993). Early unintentional introductions were likely to have been associated with the movement of live shellfish or with ballast materials (Carlton 2001). However, it was not until knowledge developed in taxonomy, biogeography, and invasion biology that the origin of many species became revealed (Elton 1958). Recently, techniques using DNA markers have provided a more precise method of tracking alien species (i.e., Pollux et al. 2003; Ashton et al. 2008). Furthermore, it has been generally acknowledged that high levels of human mobility enabled marine and brackish water aliens to become inadvertently spread by efficient, rapid transport modes with comparatively high levels of survival (Cohen and Carlton 1998; Leppäkoski and Olenin 2000; Leppäkoski et al. 2002; Minchin and Gollasch 2002; Wonham and Carlton 2005; Rilov and Crooks 2009). After becoming established, many species subsequently expanded their range from 'hubs', which involved a variety of dispersal processes (Minchin 2007a). Moreover, deliberate movements of live species intended for human consumption have also resulted in releases of alien species into the wild and included those used to promote fisheries and aquaculture (Cook et al. 2008). In addition, anthropogenic induced climatic changes will also enable the poleward dispersal and establishment of some alien species (Pedersen et al. 2011).

Lists of marine and brackish water alien species have been compiled for a number of European countries and regoins including: Azores (Cardigos et al. 2006), Belgium (Kerckhof et al. 2007), Denmark (Jensen and Knudsen 2005), Germany (Gollasch and Nehring 2006), France (Goulletquer et al. 2002), Greece (Pancucci-Papadopoulou et al. 2005), Ireland

(Minchin 2007b), Italy (Occhipinti Ambrogi 2002), the Netherlands (Wolff 2005; Gittenberger 2007), Norway (Hopkins 2002), the Baltic countries (Olenin 2005), and Ukraine (Alexandrov et al. 2007). Reports of alien species from regional seas are known for the Aegean (Zaitsev and Ozturk 2001), North (Reise et al. 1999; Gollasch et al. 2009), White (Berger and Naumov 2002), and semi-enclosed seas: the Baltic (Olenin and Leppäkoski 1999; Leppäkoski et al. 2002; Leppäkoski et al. 2009), Black (Zaitsev and Ozturk 2001; Gomoiu et al. 2002), Caspian (Zaitsev and Ozturk 2001; Aladin et al. 2002; Grigorovich et al. 2003), Marmara (Zaitsev and Ozturk 2001; Ozturk 2002), Mediterranean (Rilov and Galil 2009; Galil and Zenetos 2002; Galil et al. 2002; Golani et al. 2002; Zenetos et al. 2004; Verlaque et al. 2010), and the Wadden (Reise et al. 2005). Providing a full list of alien species is acknowledged to be extremely difficult, as this requires a specialised scientific knowledge covering a wide range of taxonomic groups, as well as regular monitoring to reveal recent arrivals. Many are either rare or cryptic and so may remain undiscovered. Those that become recognised normally do so because they are either conspicuous or cause some recognised impact, often years after their arrival and establishment. This makes the task of assigning a date for first arrival of an alien species in a particular country or region difficult. However, the present account brings together the most recent information, adds to the list of Minchin and Eno (2002), and summarises the occurrence of aliens reported from brackish and marine environments throughout Britain (i.e., coastal waters adjacent to England, Wales, and Scotland, with the exception of the Isle of Man and the Channel Islands). The earliest known reports of each alien species, up until the end of 2010, is tabulated and includes single records of species, some of which are unlikely to have survived or otherwise become established in British waters. The list does not include alien microbiota (i.e., viruses and bacteria), interstitial fauna, or species that have been distributed to Britain by natural range expansion, except by anthropogenic flotsam. In addition, cryptogens (species that cannot be reliably demonstrated as being introduced or native, see Carlton 1996) have not been included in this list. Certain species that might be expected to be considered in this account, therefore, have not been included as they are considered to be cryptogens by the authors.

Methods

The list of alien species for British marine and brackish waters was compiled from unpublished records, recent field studies, literature searches, specialist advice, and previous listings including those of Knight-Jones et al. (1975), Thorp et al. (1986), Utting and Spencer (1992), Eno et al. (1997), Eno (1998), Maggs and Stegenga (1999), Minchin and Eno (2002), Arenas et al. (2006), Brodie et al. (2007), and Cook et al. (2008). The status of marine algae follows that of the review by Brodie et al. (2007), with some additions, and for the phytoplankton follows most of the opinions of Gómez (2008). He considered that many species of phytoplankton were either previously overlooked, incorrectly described on account of their small size and morphological features, or were considered by him to be cosmopolitan.

The list presented by the present study was confined to species that exhibited certain characteristics identified as representative of an alien species (modified from Chapman and Carlton 1991; Boudourseque 1994; Ribera and Boudouresque 1995; Wolff 2005). These features included: a) the appearance of a conspicuous species not previously recorded; b) a geographic discontinuity of a species; c) a highly localised occurrence of a species; d) a recent expansion of a species from an initially localised area; e) insufficient natural dispersal modes to account for the presence of a species; f) a rapid population expansion; g) an association with pathways processes or a specific vector; h) a dependence on an alien species for part of, all of, their life cycle; i) a low genetic variability when compared with other known populations; j) where distant populations are genetically identical; k) the species belongs to a taxonomic group restricted to an area outside of where it has been found; and l) where a life history stage cannot be easily dispersed by wildlife.

The area and year of the first record(s) were used to describe the intial appearance of the alien, even though the species may have been well established at that time. In some cases, where an extensive survey has taken place, several localities may be documented as the first record for the alien species.

The pathway provided here was classified either based on direct evidence of an introduction or a ‘likely arrival mode’. The latter representing aliens that were either first reported in the same area as an identified principal

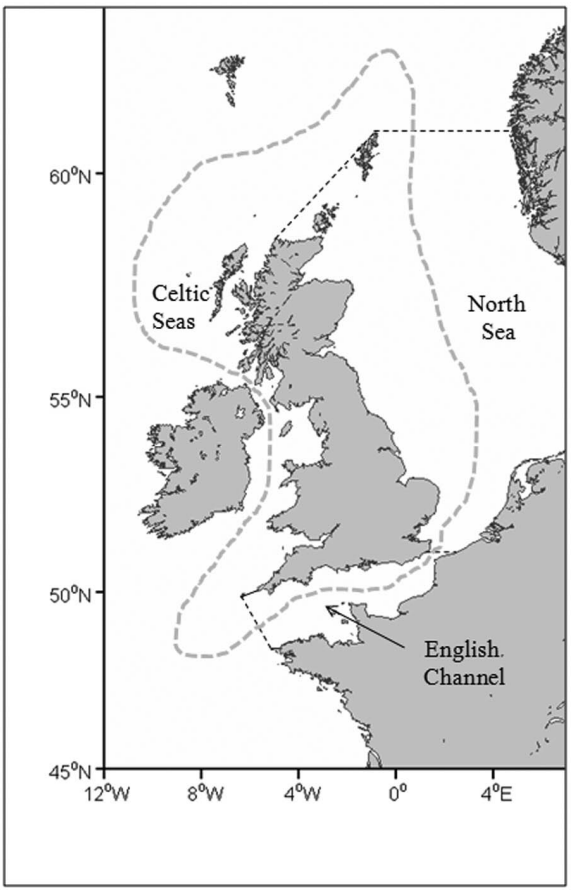

Figure 1. Map to show boundaries (dashed black lines) for the three geographic areas: North Sea, English Channel and Celtic Seas. Dashed grey line represents outer limit of waters classified as 'British' for the purpose of this study, based on UK Exclusive Economic Zone.

pathway activity, or where they, or a close taxon member, are known to have been associated with such an activity elsewhere (i.e., aquaculture, shipping) (see Olenin et al. 2010). 'Possible transmission' usually involved more than one mode of entry. A pathway was described as 'unknown', where either a large number of transmission processes might be involved, where there is no supporting evidence for any transmission mode, or where no reasonable explanation for an arrival can be deduced (Olenin et al. 2010).

Three geographic regions have been used to define the seas surrounding Britain, the English Channel, North Sea and Celtic seas (Figure 1). The delineation between the North and Celtic seas is defined as a boundary from Cape Wrath, in Scotland, to the north of the Shetland Islands (Herma Ness), and to the south of the Sognefiorden (Gollasch et al. 2009). The eastern division of the English Channel lies between Dover and the French-Belgian border (Gollasch et al. 2009), and the western division from St Agnes in the Scilly Isles to Île d' Ouessant, France. The Celtic seas include the Bristol Channel, St Georges Channel, Celtic Sea, Irish Sea, and the waters to the west of Scotland. The number of species appearing for the first time in Britain and the current status of their recent distributions has been scored in relation to their occurrence within each of the three geographic regions. In this account, a 'single locality' where a species appeared, refers to a distinct bay or inlet, or a known offshore location. Where a species is known from more than one location in a region, this is referred to as 'localities'. If it is generally distributed within one or two regions it is referred to as being 'regional', and in all three regions it is referred to as 'widespread'.

Results

Ninety alien species (Appendix 1) have been recorded for British marine and brackish waters. Of these, 31 alien species can tolerate reduced salinity. Over 64% of these alien species have established populations and could potentially act as environmental indicators for future environmental change. The remaining 32 species may be established, but no recent records exist, or there is insufficient information regarding their distribution and abundance.

The most frequent taxonomic groups are the macroalgae, annelids, arthropods, and molluscs, equating to 69 alien species (78%) (Figure 2). The number of new aliens has continued to increase since the 1930s, with approximately half having been recorded since 1970 (Figure 3). In the last 20 years, however, the rate of increase has plateaued with a similar number of species recorded, as in the previous twenty-year period.

Thirty-five alien species originated from the North Pacific, with 82% of these having become established in British waters. If this site of origin was extended to include the remaining regions of the Pacific and Indo-Pacific, this group would comprise half of all the alien species recorded (Figure 4). The second largest group comprised 22 species originating from the North-west Atlantic, of which 70% have become established

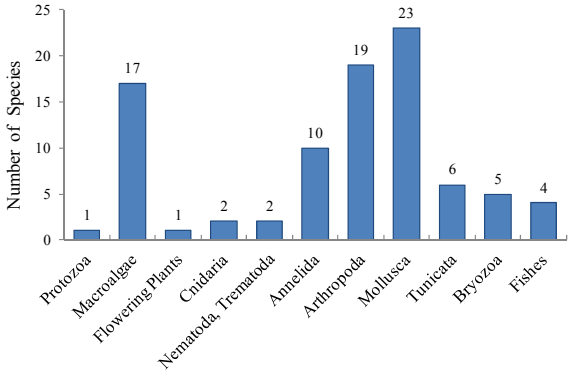

Figure 2. Taxonomic breakdown of numbers of alien species in brackish and marine environments in British waters (N=90).

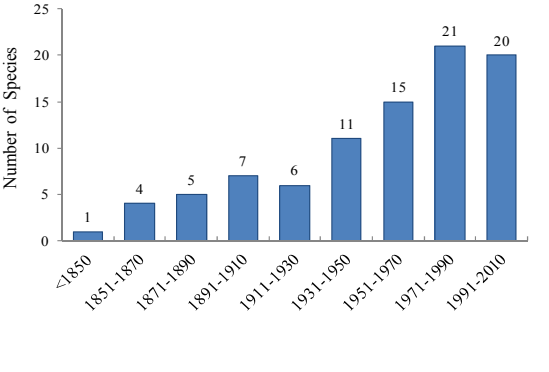

Figure 3. Number of alien species introduced into brackish and marine environments in British waters over 20 year intervals from <1850 to 2010 (N=90).

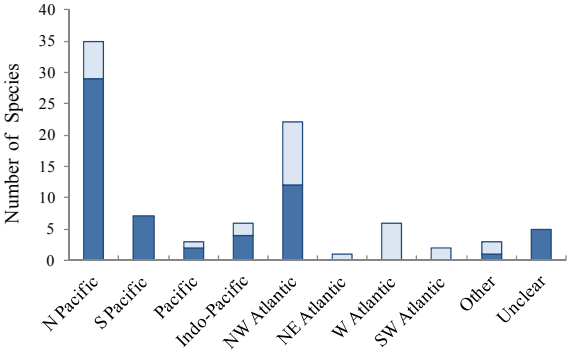

Figure 4. Native origin of alien species recorded established (dark bar) and not established (light bar) in British brackish and marine environments. Species categorised as origin 'unclear', were still classified as alien following expert advice (N=90).

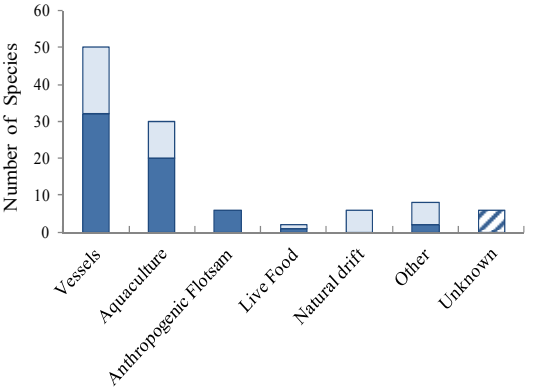

Figure 5. Pathways involved in the transmission of alien species into British brackish and marine environments. Likely arrival mode involving a single known pathway (dark bar), possible transmission pathway invoving more than one mode of entry (light bar) and unknown (striped).

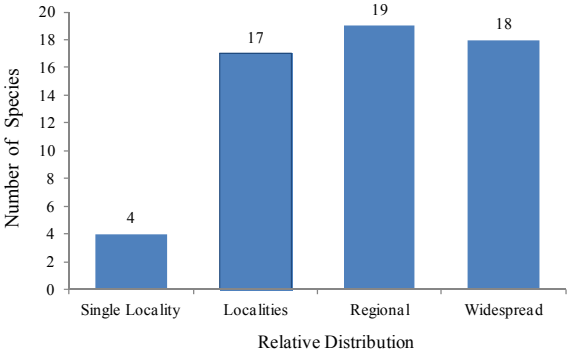

Figure 6. Relative distribution of established alien species in British brackish and marine environments.

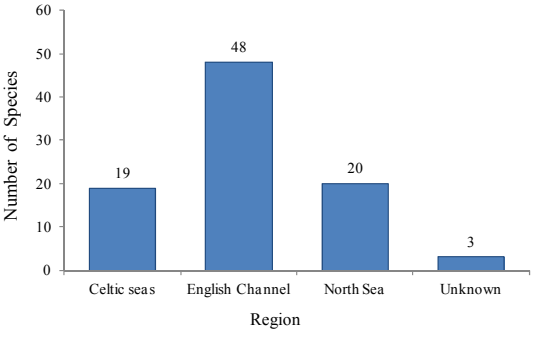

Figure 7. Region recorded as first record for alien species in British brackish and marine environments (N=90).

since their introduction. Smaller numbers of species are believed to have originated from the Mediterranean, Ponto-Caspian, and Polar seas, and are grouped within the 'other' category (Figure 4).

The most reliable evidence relating alien species to a particular pathway is where they, and their associates, have been deliberately introduced. Where only a single pathway process has been identified (see Olenin et al. 2010 for definitions), vessels and aquaculture activities were considered responsible for at least 47% and 30% of introductions, respectively (Figure 5). Where the mode of arrival could have been *via* more than one pathway, then vessels and aquaculture activities were still cited as major vectors along with other modes of transmission. Anthropogenic flotsam was responsible for the introduction of 9% of the alien species. Where a pathway is defined as 'other', it included: deliberate introduction for planting purposes (e.g., *Spartina townsendii* var. *anglica*); unintentional importation with timber (e.g., *Dreissena polymorpha*); and secondary spread (e.g., *Ensis directus*, following intial introduction into the German Bight in 1979, von Cosel et al. 1982).

The majority of established alien species in British waters were recorded from more than one locality (93%), although their distribution may still be contained within relatively small areas. Over 30% of the alien species were reported as widespread and 33% as regionally established (Figure 6). Forty-eight alien species were first recorded in the English Channel (54%), despite this being the smallest of the three geographic regions. The number of first reported sightings for the North and Celtic Seas were similar, with 23% and 20%, respectively (Figure 7).

Discussion

Marine and brackish water alien species in British waters

Ninety alien species have been identified from marine and brackish environments in British waters, and 58 of these are now established. It is almost certain that this established number is underestimated, as many species are only recognised as aliens some years after their introduction. Further, alien species that were recorded as being "present" during the last decade may yet become established, in some cases aided by changes in environmental conditions. Alien macroalgae and invertebrates dominate the introduced flora and fauna, particularly the red algae, polychaete worms, molluscs, and crustaceans. This result is similar to earlier reviews of non native species in Britain and many other European countries (e.g., Eno et al. 1997; Minchin and Eno 2002; Occhipinti Ambrogi 2002; Olenin 2005; Kerckhof et al. 2007). Alien echinoderms are not known in Britain and the status of two sponge species is unclear. There are four bryozoan additions to those included in previous studies undertaken by Eno et al. (1997) and Minchin and Eno (2002); *Bugula neritina*, *B. simplex*, *B. stolonifera,* and *Watersipora subtorquata* (Ryland et al. 2011). The dominant alien taxonomic groups tend to consist of a number of highly opportunistic and resilient species, which can either attach to, or otherwise be carried by, various vectors for extended periods of time enabling their transfer to new geographic regions.

Not all alien species become established once introduced to a new region. In this study, nearly 40% of species introduced are not known to have become established in British waters. Of these species, a few were introduced for commercial cultivation (e.g., the American oyster *Crassostrea virginica*). Other species were recorded from only one locality with no recent records, suggesting that the environmental conditions may have been unsuitable for establishment (e.g., the polychaete *Hydroides dianthus* and the bivalve *Brachidontes exustus*). In addition, some species were expected to have established populations in Britain, but have not been reported, including: the chironomid *Telmatogen japonicas*, often associated with navigation buoys and present on the coastline of northern Europe (Raunio et al. 2009) and on the Irish coast (Murray 2000); the copepod *Mytilicola orientalis*, a gut parasite of bivalves; and the copepod *Myicola ostreae* that lives on the gills of the Pacific oyster *C. gigas*. Both copepods have been found in Ireland (Holmes and Minchin 1995), France (Goulletquer et al. 2002), and the Netherlands (Wolff 2005), but have not yet been recorded in Britain.

The greatest diversity of alien species was recorded from the English Channel, with the Solent, Southampton Water, and Plymouth supporting particularly high numbers. This is consistent with the findings of Eno et al. (1997), Minchin and Eno (2002), and Arenas et al. (2006). This last study, involved the survey of

twelve marinas along the south coast of England, where twenty alien species were found. The great majority of these occurred in marinas adjacent to the Solent (e.g., Southsea, Gosport, Southampton, and Hamble Point). These results suggest that regions with large volumes of shipping movements (e.g., cross-Channel ferries, commercial, and recreational vessels) and aquaculture activities, which have been undertaken for many years, are likely to be high risk sites for future introductions.

There has been a continued increase in the number of records of alien species over the last 160^{+} years, which is consistent with findings from many other countries (Gollasch and Nehring 2006; Kerckhof et al. 2007; Minchin 2007a). This typically reflects an increase of international trade over the same period, which has become more rapid and varied (Minchin and Gollasch 2002; Hulme 2009). In addition, there is a greater awareness as more researchers gain a greater understanding of biogeography and as more identification material becomes more freely available to the public. From 1991 to 2010, however, a similar number of aliens was recorded compared with the previous 20 year period. This may reflect improved anti-fouling practices for commercial vessels in British waters and the introduction of European legislation to control aquaculture transfers. However, with the ban of tributyltin in antifouling paints in 2008, a further rise in the number of aliens being recorded may take place in the next few decades, on account of the more favourable conditions enabling establishment (Minchin 2010).

Native origin of alien species in British waters

The majority of alien species introduced to British waters were found to originate from the North Pacific, particularly the north-west (e.g., Asia and Japan) followed by the North-west Atlantic (e.g., east coast of the USA). This result is consistent with the findings of Eno et al. (1997) and Minchin and Eno (2002), suggesting that introductions from regions with similar temperature regimes to Britian are more likely to become established and widespread, as they would be physiologically adapted to the environmental conditions experienced in the recipient waters. Certain species, however, such as the zebra mussel *Dreissena polymorpha*, which originates from the Ponto-Caspian region (Pollux et al. 2010), and the tubeworm *Ficopomatus enigmaticus*, which originates from the Indo-Pacific (Zibrowius and Thorp 1989) have high physiological plasticity and are able to tolerate a wide range of environmental conditions. For some alien species, it is unknown whether their introduction into British waters has been direct from their country of origin or the result of a secondary introduction (i.e., *Caprella mutica*, Ashton et al. 2006a). The broad range of regions of origin reflects the extent of global trade.

Transmission vectors of alien species

The two principal pathways for the introduction of alien species into British waters, based on the present records, are the transmissions by vessels and aquaculture activities. The former involves transport via commercial or recreational vessel hulls and ship sea-chests (used during ballast water exchange), either as sessile (fouling), boring, vagile, or clinging species (Minchin et al. 2006). Alien species introduced by these vectors include a wide range of taxa, including: macroalgae (e.g., *Undaria pinnatifida*, *Asparagopsis armata*), barnacles (e.g., *Austrominius modestus* and *Balanus amphitrite*), bryozoans (e.g., *Tricellaria inopinata* and *Watersipora subtorquata*), and ascidians (e.g., *Didemnum vexillum*, *Botrylloides violaceus*, and *Styela clava*). Most of these species are commonly found in ports and marinas (Ashton et al. 2006a; Arenas et al. 2007; Griffith et al. 2009) and in neighbouring countries. Slow moving vessels (e.g., barges and de-commissioned vessels) or ships berthed in one place over long periods (e.g., tall ships) are particularly prone to transmitting alien species. Barges have been implicated in the transmission of *Bonamia ostreae* between English south coast bays (Howard 1994) and de-commissioned ships returning from the Korean War may have introduced the Asian tunicate *Styela clava* in 1953 (Minchin and Duggan 1988). Ballast water has also been highlighted in numerous studies as an important transmission vector for alien species, particularly phytoplankton. Eno et al. (1997) suggested that a number of Bacillariophyta, such as *Odontella sinensis* and *Coscinodiscus wailesii* had been introduced via ballast water. However, the status of these and several other phytoplankton species has been recently changed from alien to cosmopolitan (Gómez 2008) and so these species were omitted from the British alien species list.

Aquaculture was identified as the second major pathway for the importation of alien

species to British waters. Introductions have occurred, either through the deliberate movement of a species for culture (Utting and Spencer 1992), or unintentional introduction as a 'hitch-hiker' on bivalve molluscs (e.g., *Crepidula fornicata*), or as an introduced parasite (e.g., the nematode *Anguillicoloides crassus*). Some of the deliberately introduced species, including the oysters *Crassostrea rhizophorae* and *C. virginica*, did not become established in British waters. In contrast, the bivalves *C. gigas* and *Tiostrea chilensis* (Utting and Spencer 1992), introduced to Britain through a quarantine system in the 1960s, are established, with *C. gigas* forming extensive reefs outside of culture sites in the English Channel (Couzens 2006). When first introduced to Britain, temperatures were insufficient for recruitment of *C. gigas*, the subsequent increase in summer temperatures are thought to be responsible for its greater recruitment in many regions of northern Europe, including Britain (Reid and Valdés 2011).

Other vectors identified as introducing alien species into British waters included; anthropogenic flotsam, which brought the bivalve *Brachidontes exustus* (J Light pers. comm.) and the barnacle *Balanus trigonus* (Turk 1988), neither are known to have become established. The early trade in timber resulted in the introduction and establishment of the zebra mussel *Dreissena polymorpha* from the Baltic Sea (Kerney and Morton 1970). For many species, however, it is still unclear how they arrived, as there are several possible transmission routes that might include secondary spread from neighbouring countries. Natural dispersal mechanisms, such as wind-blown drift, are almost certainly involved in the secondary spread of macroalgae that have air bladders, such as *Sargassum muticum* (Harries et al. 2007), or those with a buoyant thallus as in the case of *Colpomenia peregrina* (Mineur et al. 2008).

Introduced or a range extension?

For several species, it is uncertain whether distributions in new localities arise out of human mediated dispersal, natural range expansion, or vagrancy. For example, not included as an alien is the copepod *Acartia* (*Acartiura*) *margalefi* Alcaraz, 1976, originally described from Ría of Vigo, Spain, and reported from Southampton Water, and Horsea Lake, Portsmouth (English Channel) by Castro-Longona and Williams (1996). It is now known from: Svartatjönn, Norway; Killary Harbour, Ireland; Portsmouth and Southampton, England; Brest, France; and across the Mediterranean to the Black Sea. With these recent records, it now seems improbable that this copepod was introduced into Britain and even more unlikely to be a range extension northwards. Instead the natural distribution of *A. margalefi* within the north-east Atlantic is only now becoming evident.

The native range of two brachyuran crabs, *Eriphia verrucosa* (Forskål, 1775) and *Pachygrapsus marmoratus* (Fabricius, 1787), was from the Black Sea, Mediterranean Sea, and the Eastern Atlantic Coast from the Azores northwards to the west coast of Brittany, France (d'Udekem d'Acoz 1999). Both species have been reported from the English Channel. *Pachygrapsus marmoratus* from Netley, Southampton Water and the Teign Estuary (Ingle and Clark 2008), and *E. verrucosa* from Whitesand Bay, Cornwall (Daniel 2004; Herdson 2004, 2005) and Jersey, but neither species was found in reproductive condition. The single capture of *E. verrucosa* in the locality of Whitesand Bay likely represents a vagrant because this stretch of coast has been well sampled by the Marine Biological Station at Plymouth (e.g., Marine Biological Assocation 1957). Populations of *P. marmoratus* (Ingle and Clark 2008; Dauvin 2009) occurring along the Brittany and Normandy coasts of France, as well as in Jersey, do not appear to be viable but might have been introductions associated with stock movements of oysters from further south (Ingle and Clark 2008). Both are native to the north-western Atlantic coast of France, and it is not certain whether their presence on the south-west coast of Britain represents a northerly natural range extension.

Impact of alien species in British waters

Williams et al. (2010) estimated the direct cost of alien species to marine industries in Great Britain as approximately £40 million per year. However, this is thought to be an underestimate because native and non-native species are generally not distinguished by managers during pest management activities. Moreover, species known to have caused severe economic impact to the oyster (Brown et al. 2006) and eel fisheries (Kennedy and Fitch 1990) (i.e., *Bonamia ostreae* and *Anguillicola crassus*, respectively) were not included in the study byWilliams et al. (2010). For the majority of alien species in Britain, the

impacts are unknown, however; certain species have had a considerable negative effect. For example, there have been extensive habitat modifications to mud flats caused by *Spartina anglica* (Frid et al. 1999) and bank erosion has become a problem in the Thames estuary due to burrowing by the Chinese mitten crab, *Eriocheir sinensis* (Clark et al. 1998). The alien tunicates *Styela clava* and *Didemnum vexillum* have had a considerable impact on aquaculture activities elsewhere (Bourque et al. 2007; Coutts and Forrest 2007). *Crassostrea gigas* has formed extensive reefs, competing with mussels and creating localised fouling of shallow inlets and bays on some North Sea coasts (Wolff and Reise 2002; Reise et al. 2005; Gollasch et al. 2009; Wrange et al. 2010). At some future time, such reef formations may result in more extensive fouling of shallow waters around the British coastline.

Future distribution patterns of alien species in British waters

The expected overall trend for the next few decades is a change in climate that will affect the marine environment (Reid and Valdés 2011). The predicted changes will challenge the physiological limits of some species, while providing opportunities for others. For example, aliens requiring higher temperatures for reproduction in summer may now be able to colonise a particular region following an introduction (Stachowitz et al. 2002), as has happened with *C. gigas* (Pedersen et al. 2011). Production of this species was once dependent upon spat produced in shellfish hatcheries, and now this species recruits in the wild. This has been a gradual development with settlements of individuals of *C. gigas* in North Wales first noted in the 1990s and, on the south coast of England, natural recruitment has become more intense since the previous study by Spencer et al. (1994). Similarly, the Manila clam *Venerupis philippinarum* now recruits in Poole Harbour and in Southampton Water (Jensen et al. 2005). Conversely, aliens that would have typically succumbed to cold conditions, as happened on the south coast of Britain in the 1960s (Crisp 1964), may well now survive and expand their range as warmer winter sea conditions become more common. In general, though there is likely to be a northwards movement of species arriving in Britain, as observed in the Mediterranean Sea (Occhipinti Ambrogi 2007). Examples of recent poleward expansions of alien species (Reid et al. 2009) include *S. muticum* and *S. clava* (Ashton et al. 2006b). Whether these movements are due to increases in summer seawater temperatures or new opportunities (or both), remains unknown.

Northwards range expansion of species in currently found in southern Europe to Britian may be expected in the future. Alterations of current flow in the north-east Atlantic and Polar Sea (Greene and Pershing 2007), and retractions of Arctic sea-ice in summer (Brigham and Ellis 2004) as a consequence of climate change, may also lead to a greater usage of seasonal shipping routes between the North Atlantic and North Pacific. This might allow the transmission of cool-water North-Pacific species from the biologically richer North Pacific Ocean to the North Atlantic and extend southwards to British waters (Minchin and Gollasch 2003).

Improvements in the identification of species using genetic studies are likely to reveal aliens which may be present, but not yet detected, in British waters and may raise questions as to the status of some species previously presumed to be native. Genetic studies should also assist in the determination of whether a species has either been introduced or is an overlooked glacial relict (Haydar et al. 2011), together with the identification of alien viruses and microbiota, which are distributed world-wide (Drake et al. 2007) and have undoubtably been overlooked. Furthermore, disease-causing organisms need to be examined in more detail, as there is much confusion as to whether sporadic events are due to endemic or alien biota. For example, the wasting disease of the eel-grasses, caused by the slime mould *Labrynthula zosterae*, may have been introduced, as this event appeared in different world regions, and these slime moulds frequently occur in ships' ballast sediments (Hülsmann and Galil 2002). However, the origin of this disease still remains unknown. Furthermore, fouling species associated with vessels could harbour parasites or disease agents that might threaten biosecurity, not just in Britain, but to northern Europe. This remains an area for study.

Conclusion

Ninety alien brackish and marine species are considered to be introduced to British waters, with 58 regarded as being established. Many additional species have almost certainly yet to be reported. Several of the identified aliens are

considered to be of high impact, either environmentally and/or economically, and some of these continue to expand their range. The high degree of human mobility and expansion of European trading routes, as well as continued trade internationally, will result in further species being introduced. Vessel movement and aquaculture continue to pose special risks. Management practice in associated industries should be examined closely to minimise unintentional movements of aliens. With a policy of open trade throughout the European Union and the influence of climate change, it is likely that further alien species will be inadvertently or deliberately brought to Britain. The key to the successful management of this issue, therefore, will be the early detection through regular monitoring and effective control or eradication of any aliens which are likely to cause serious economic and/or environmental impact in British waters.

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Supplementary material

The following supplementary material is available for this article.

Appendix 1. List of alien species recorded from British brackish and marine waters.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2013/Supplements/AI_2013_Minchin_etal_Supplement.pdf