JOINT NATURE CONSERVATION COMMITTEE

Non-native marine species in British waters: a review and directory

Edited by

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Coastal counties, regions, water bodies and other major marine localities in Great Britain referred to in the text.

Note. Following recent local government reorganisation, some counties and regions changed to unitary authorities with altered boundaries.

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Summary

The study reported here was undertaken to collate details and review information about introductions of marine fauna and flora to Great Britain (England, Scotland and Wales). The focus of this review is on nature conservation and the work will be used to formulate policy on marine introductions in relation to nature conservation interests.

The study evaluates *non-native* macro fauna and flora, which have been introduced from outside their natural range and have become established in the wild in British waters. This report evaluates their origin, date and method of introduction, the reasons for their success, rate of spread, current distribution, actual and potential effects on native ecosystems and nature conservation as well as commercial interests, and methods of control. Micro-organisms (< 20 µm) are not considered.

Fourteen species of marine alga (or 15 taxa including two subspecies of a single species of green alga), five diatoms, one angiosperm and 30 invertebrates have been identified as non-native and aspects of their introduction and subsequent effects described. The majority of these 50 species are red algae, polychaete worms, crustaceans and molluscs. No non-native sponges, bryozoans or echinoderms have been found in British waters. Although the frequency with which introduced species have been recorded in Europe has increased with time, there is no trend in the number of non-natives which have become established in Britain. Species have been introduced directly from primary sources or areas within their natural range or from secondary sources to which they had previously been introduced. In general, species were found to have only become established if they were introduced from similar latitudes of either hemisphere. More than half the total number of species described here are considered to have been introduced to Britain in association with shipping, whilst half of the non-native marine algae found in Britain are believed to have been introduced to Europe in association with deliberate introductions of shellfish for mariculture.

Of the species deliberately introduced for aquaculture, only some of the bivalve molluscs have become established in the natural environment beyond the confines of their cultivation.

The success of the non-natives described here has, where known, been due to a combination of reasons. Of the species that have spread, the marine algae did so fairly rapidly, while the invertebrates tended to spread more slowly. The method of spread, e.g. in association with shipping, was often the same as their method of introduction for both fauna and flora.

The direct effects of non-native species on the marine environment in British waters are in general not as detrimental as reported from elsewhere in the world. Commercially, some economically important species have been introduced, but some associated pests and parasites adversely affecting native species have also been unintentionally introduced. Control methods, where applied to nuisance species, are fairly ineffective and no non-native marine species have yet been successfully eradicated from British waters. The different aspects of the biology and etiology of non-natives are discussed in relation to determining their presence and monitoring their distribution, and developing ways of avoiding further introductions.

Part 1: Review of non-native marine species in British waters

1. Scope of the study, methods and definitions employed

1.1. Introduction

The introduction of non-native species to a marine ecosystem and their subsequent establishment may cause effects ranging from the almost undetectable to the domination and displacement of native communities. Introductions may also bring with them diseases and may adversely affect a range of interests from commercial use of the marine environment to wildlife conservation. It was concern over potential effects of introductions that initiated this review which primarily focuses on nature conservation.

World-wide investigations of introduced marine species have mainly focused on specific methods of introduction, for instance the work of Carlton (1985) on ballast water introductions. Marine species introduced to North Atlantic waters are currently being reviewed by the International Council for the Exploration of the Sea, through its working group on Introductions and Transfers of Marine Organisms (ICES in prep.).

A recent workshop on introduced species in European coastal waters summarised the European situation (Boudouresque, Briand & Nolan 1994). For the British Isles, Farnham (1980, 1994) reviewed the introduction of marine algae to southern Britain; and Zibrowius & Thorp (1989) discussed the introduction of serpulid and spirorbid polychaetes. Boalch (1994) reviewed the introductions of planktonic species to Europe with particular reference to Britain. In addition, several other geographically restricted lists of non-native marine species have been produced by various other authors. There is, however, no overview of all marine introductions to British waters.

The present study was undertaken for the Joint Nature Conservation Committee (JNCC), the body constituted by the Environmental Protection Act 1990 to be responsible for research, advice and the setting of common standards on nature conservation at both UK and international levels. The work will be used to inform policy-making on marine introductions in relation to nature conservation interests. The scope of this study has been restricted to Great Britain (England, Scotland and Wales) as comprehensive information has been hard to obtain specifically for Northern Ireland. However, an equivalent, complementary study is planned for the whole of Ireland.

The present study evaluates the origin, date and method of introduction, the reasons for the success, rate of spread, current distribution, actual and potential effects on native ecosystems and nature conservation as well as effects on commercial interests and methods of control of non-native marine species. The first part reviews available information and is based on information contained in part two, a directory containing information on each species. Policies and legislation relating to the introduction of marine species to British waters and world-wide have been considered. In this context ways of minimising potential future threats to nature conservation interests arising from introductions are identified. A summary of the findings of this study is also available (Eno 1996).

Regions and counties referred to in the text, as indicated on the map at the front of this review, are based on the old local government structure. In Scotland and Wales a system of unitary authorities was created on 1 April 1996; in England more limited changes have been taking place leading to the creation of unitary authorities in some areas. Following reorganisation local government boundary changed, so some of the areas referred to in the text may no longer exist.

Determining which species are introduced by the activities of man is fraught with problems; not least the consideration that movement of species by artificial means, principally boats, has been in process for millennia, far longer than taxonomic records of species have been kept. There is, additionally, often a delay between a species being introduced and its being confirmed as present and established. Difficulties in identifying some species, or a lack of realisation that they have been introduced, have led to inaccurate records being kept. Only sometimes has it been possible to rectify mistakes by re-examination of collections and specimens. The taxonomy used in the directory is based upon that applied in Howson & Picton (1997).

1.2. Collection of information

A questionnaire (see Annex 1) was distributed widely to British marine biologists including targeted marine specialists with knowledge of particular taxonomic groups. Information was also drawn from an extensive literature search. The data collected on marine macro-fauna (specifically invertebrates) and flora are reviewed here. Micro-organisms are not considered despite there being examples which are marine and non-native to Britain, e.g. *Bonamia ostreae* which produces the disease bonamiasis in flat oysters - its spread around the UK since 1982 is documented by Hudson & Hill (1991).

Research projects have also been commissioned as part of the current project to obtain information on introduced algae and fish (Maggs & Birkett in litt.; Swaby & Potts in litt.).

1.3. Definitions of introduced species

A number of definitions of introduced species have been provided by authors (e.g. from the British perspective: UK Committee for International Nature Conservation 1979; Jarvis 1980; Stubbs 1988). However, that of Carlton (1987) is probably the most significant in this context as it specifically relates to the introduction of marine species. It states that "introduced species are those taxa transported by human activity to regions where they did not exist in historical times". The study detailed here does not, however, attempt to include all marine and brackish water introductions that arrive. Comprehensive coverage can only be expected for those species that have become established. The definitions given below are used in this study.

Non-native species: A species that has been introduced directly or indirectly by human agency (deliberately or otherwise) to an area where it has not occurred in historical times[1] and which is separate from and lies outside the area where natural range extension could be expected. The species has become established in the wild and has self-maintaining populations. The term also includes hybrid taxa derived from such introductions.

Non-established introductions: These are species that are introduced through the agency of man but have not become established and are incapable of establishing self-sustaining or self-propagating populations without deliberate intervention by man. (They are also referred to as 'alien species'.)

It is recognised that self-sustaining populations may require a critical mass or inoculum to build up over time, so there may be conversion from non-established introduction to non-native species.

Other definitions are contained in the glossary for a variety of terms including fouling, natural range, recent colonist, and vagrant.

[1] "In historical times" is taken as being since 5000 years before present.

2. The introduction of species

2.1. The species

Non-native marine species

The 15 marine algae (including two subspecies of a single species of green alga), five diatoms, one flowering plant and 30 invertebrates which are identified by the current work as non-native in British waters are listed in Table 1. Further details of each are contained in Part 2. A taxonomic break-down of marine non-native flora and fauna (invertebrates) is given in Figure 1. The taxa most frequently recorded are red algae, polychaete worms, crustaceans and molluscs. A commissioned research project on algae in 1994 catalogued fifteen taxa non-native to British waters (although one of these species has now been withdrawn by the original proponent) and a further two non-native to European waters outside Britain (one of which has subsequently arrived in Britain) (Maggs & Birkett in litt.). A research project on fish revealed no species which are considered to be truly non-native (Swaby & Potts in litt.).

The major phyla not represented in the results of the current project are the Porifera, Bryozoa and Echinodermata, together with nine further smaller phyla, listed below. The lack of non-native echinoderms is evident in other studies around the world; only one species has been recorded in Australian ballast water (Hutchings, van der Velde & Keable 1987) and none in the Swedish Baltic (Jansson 1994). There was a surprising lack of recorded non-native bryozoans. Dr Peter Hayward (pers. comm.) suggests that there are a number of species of Bryozoa which are known to occur only around ports and harbours in Britain. He considers these have probably been introduced in historical times, yet the necessary evidence to classify them as either native or non-native is lacking. Of such bryozoan species, *Bugula stolonifera* is the foremost candidate for possible consideration as non-native in British waters. It is known that bryozoans have been transported with oysters to the north coast of France (Zibrowius 1991).

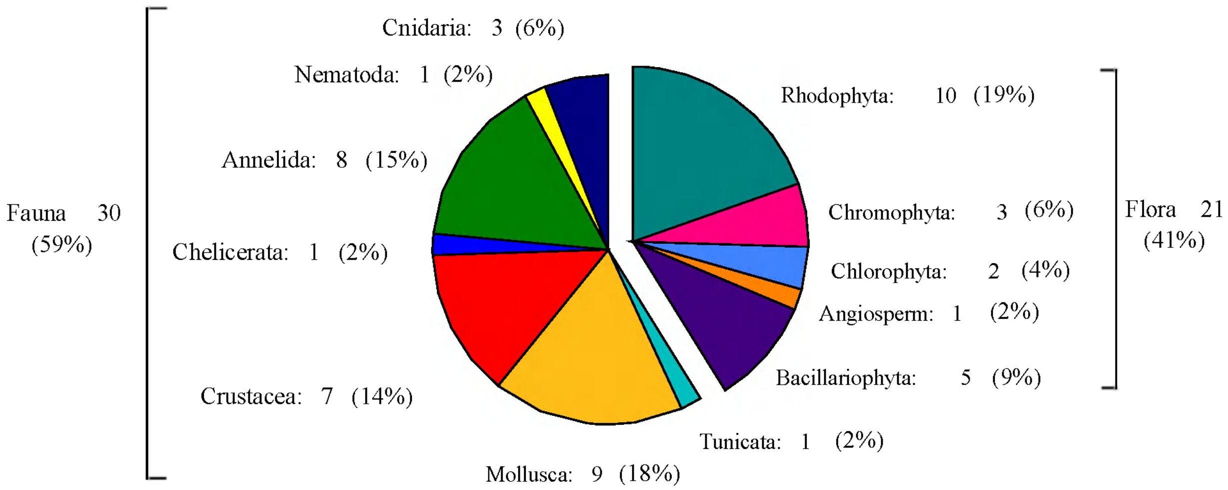


Figure 1. Number (and percentage) of non-native taxa in British waters, presented by phylum. Phyla not included here do not appear to contain any conclusive non-native species.

Phyla not represented by non-native species recorded in British waters:

Porifera, Ctenophora, Nemertea, Priapula, Entoprocta, Pogonophora, Siphuncula, Echiura, Brachiopoda, Bryozoa, Phoronida, Echinodermata.

Table 1. Non-native marine taxa found in British waters

a) Non-native marine flora which have been recorded in British waters:

Division	Class	Species (or subspecies)
Bacillariophyta	Coscinodiscophyceae	*Thalassiosira punctigera* (Castr.)
		Thalassiosira tealata (Takano)
		Coscinodiscus wailesii Gran & Angst
		Odontella sinensis Grun.
	Bacillariophyceae	*Pleurosigma simonsenii* Hasle
Rhodophyta	Rhodophyceae	*Asparagopsis armata* Harvey
		Bonnemaisonia hamifera Hariot
		Grateloupia doryphora (Montagne) Howe
		Grateloupia filicina var. *luxurians* A. & E.S. Gepp
		Pikea californica Harvey
		Agardhiella subulata (C. Agardh) Kraft & Wynne
		Solieria chordalis (Agardh) J. Agardh
		Antithamnionella spirographidis (Schiffner) Wollaston
		Antithamnionella ternifolia (J.D. Hooker & Harvey) Lyle
		Polysiphonia harveyi Bailey
Chromophyta	Phaeophyceae	*Colpomenia peregrina* (Sauvageau) Hamel
		Undaria pinnatifida (Harvey) Suringer
		Sargassum muticum (Yendo) Fensholt
Chlorophyta	Chlorophyceae	*Codium fragile* (Suringar) Hariot subsp. *atlanticum* (A. Cotton) Silva
		Codium fragile (Suringar) Hariot subsp. *tomentosoides* (van Goor) Silva
Plantae	Magnoliopsida	*Spartina anglica* C.E. Hubbard

b) Non-native marine invertebrates in British waters

Phylum	Class	Species
Cnidaria	Hydrozoa	*Gonionemus vertens* A. Agassiz 1862
		Clavopsella navis (Millard 1959)
	Anthozoa	*Haliplanella lineata* (Verrill 1869)
Nematoda	Dracunculoidea	*Anguillicola crassus* Kuwahara, Niimi & Itagaki 1974
Annelida	Polychaeta	*Goniadella gracilis* (Verrill 1873)
		Marenzelleria viridis (Verrill 1873)
		Clymenella torquata (Leidy 1855)
		Hydroides dianthus (Verrill 1873)
		Hydroides ezoensis Okuda, 1934
		Ficopomatus enigmaticus (Fauvel 1923)
		Janua brasiliensis (Grube 1872)
		Pileolaria berkeleyana (Rioja 1942)
Chelicerata	Pycnogonida	*Ammothea hilgendorfi* (Böhm 1879)
Crustacea	Maxillopoda	*Elminius modestus* Darwin 1854
		Balanus amphitrite Darwin 1854
		Acartia tonsa Dana 1848
	Ostracoda	*Eusarsiella zostericola* Cushman 1906
	Eumalacostraca	*Corophium sextonae* Crawford 1937
		Eriocheir sinensis H. Milne Edwards 1854
		Rhithropanopeus harrisii (Gould 1841)
Mollusca	Gastropoda	*Crepidula fornicata* (Linnaeus 1758)
		Urosalpinx cinerea Say 1822
		Potamopyrgus antipodarum (J.E. Gray 1843)
	Pelecypoda	*Crassostrea gigas* (Thunberg 1793)
		Tiostrea lutaria Hutton
		Ensis americanus (Gould in Binney 1870)
		Mercenaria mercenaria (Linnaeus 1758)
		Petricola pholadiformis Lamarck 1818
		Mya arenaria (Linnaeus 1758)
Tunicata	Ascidiacea	*Styela clava* Herdman 1882

Table 2. Some non-established introductions (aliens) which have been recorded in British waters.

Phylum	Species	Common name	Comment
Annelida	*Hydroides elegans*	-	Died out.
	Pilumnoides inglei	-	Not recorded since 1913.
Crustacea	*Brachynotus sexdentatus*	Mediterranean crab	No longer present (formerly in Queen's Dock, Swansea).
	Neopanope sayi	Caribbean mud crab, Mud crab	No longer present (formerly in Queen's Dock, Swansea).
	Penaeus japonicus	-	Only three records in Britain to date (not established).
	Callinectes sapidus	Blue crab	Only two records in Britain to date (not established).
	Homarus americanus	American lobster	Only three records in Britain to date (not established).
	Crassostrea virginica	Amercian oyster	Introduced to Britain for relaying 1870s - 1939 and briefly in 1984; never became established.
	Tapes philippinarum	Manila clam	Held for aquaculture purposes only, not established in wild.
Mollusca	*Choromytilus chilensis*	Chilean mussel	Not established in the wild.
	Crassostrea brasiliensis	Mangrove oyster	Not established in the wild.
	Rapana venosa	Japanese whelk	Single live catch from Silver Pits, south of Dogger Bank in the North Sea in 1991 (Anon 1992).
	Aulacomya ater	Magellan mussel	Recovered from deep water in the Moray Firth in 1994, believed to have fallen off a barge (McKay 1994).
Bryozoa	*Bugula neritina*	-	No longer established in wild.
Vertebrata	*Oncorhynchus gorbuscha*	Pink or humpback salmon	Some escapes to the wild but not self-sustaining.
	Oncorhynchus kisutch	Coho salmon	Rare escapes to the wild.
	Oncorhynchus keta	Chum salmon	Once recorded from the wild.
	Oncorhynchus mykiss	Rainbow trout	Primarily freshwater species but migratory (steelhead) crosses, not self-sustaining.

Species which have been considered as potential non-natives, but for which compelling evidence is lacking, are listed in Table 2.

Non-established introductions

Many examples of non-established introductions are species introduced for commercial cultivation which rely on populations being maintained through importation of hatchery seed. Others include species which have previously been established as breeding colonies, usually with the support of outside influences, such as thermal effluent, but under changed circumstances (for instance with the closure of a power station) are no longer established in the wild. Some of these are listed in Table 2. There are many non-established introductions which survive only briefly in British waters, many of which probably go undetected; consequently this list is far from comprehensive.

A brackish water zebra mussel *Mytilopsis leucophaeta* has very recently been identified from Cardiff docks, in South Wales (Oliver, Mettam & Holmes in press). The full size range of individuals has been found, but confirmation is still awaited that it is established in Wales. This species was described from Belgium (under a different name) in 1835 and is present in other European countries, but it is not clear whether it has arrived in Britain from the continent or its native America. This find is of particular interest as a fresh water member of the zebra mussels (Dreissenoidea), *Dreissena polymorpha*, has caused considerable problems in the North American Great Lakes by smothering other species, habitats and commercial property. In the Aquatic Nuisance Prevention and Control Act 1990, which was enforced to prohibit the release of freshwater ballast into the Great Lakes, it was estimated that the effects of the zebra mussel will have cost $5,000 million by the year 2000.

Cryptogenic species

Carlton (1996a) defines a cryptogenic species as a species which is not demonstrably native or introduced. Assigning species as cryptogenic has often been neglected, yet where this categorisation has been considered, it is surprising how many there are, with up to 33% of species recorded in San Francisco Bay being cryptogenic (Carlton 1996a). This indicates that estimates of non-natives will always be underestimates as at least some cryptogenic species will be non-native. Taxonomic uncertainties can lead to introductions being regarded as new species, such as the leathery sea squirt *Styela clava*, initially considered as a new species by Carlisle (1954); such errors are often perpetuated. On the other hand, Zibrowius (1991), in his discussion of exotic species in the Mediterranean, indicated that in exceptional cases, some native species had mistakenly or hypothetically been considered as introductions.

The parasitic copepod *Mytilicola intestinalis* has not been included as a non-native species to Britain, despite its consideration by some authors as an introduction associated with the import of commercial shellfish (International Council for the Exploration of the Sea 1972; Utting & Spencer 1992). This species was first described in 1902 from the Mediterranean; subsequent records from around Europe seemed to coincide with an active search for it amongst shellfish deposits. There is no doubt that this species could be moved around with shellfish deposits as it is an internal parasite of mussels. However, its biology suggests that it is a boreal species and Britain is easily within its potential natural range (Dr Mike Gee pers. comm.). Consequently it satisfies the criteria to be cryptogenic.

Other cryptogenic species in British waters include the bryozoans *Bugula stolonifera* and *Bowerbankia gracilis*. The origin of the former is unclear. However, it occurs in ports all over the world (including Swansea docks), while the latter is a taxonomically difficult species of which certain subspecies may be non-native. The sponge *Suberites massa* invariably occurs in harbour areas which suggests it is an introduction, although further evidence is lacking. The barnacle *Solidobalanus fallax*, recently found off Plymouth, Devon, and described as a new species (Southward 1995), is also cryptogenic.

Vagrant species

Vagrant species are often confused with those which are truly non-natives. Vagrants are individuals of a species which, by natural means, move from one geographic region to another outside their usual range, or away from usual migratory routes, and which do not establish a self-maintaining, self-regenerating population in the new region. There are many marine fish which are vagrant to British waters (Swaby & Potts in litt.). There are also vagrant marine mammals and turtles. These are not considered in the present report.

Recent colonists

Species which extend their range by natural means may also mistakenly be referred to as non-native. Natural colonisations are frequently the result of changes in local environmental conditions, often due to slight climatic variations, so that a species normally occurring outside the area under consideration can extend its range and move into that area (Boalch 1994). An uncontested example of range extension is the alga *Laminaria ochroleuca* which is believed to have crossed the English Channel to south-west England in the warm period prior to 1940 and it has persisted, although after cold winters its distribution is restricted (Boalch 1994).

2.2. Dates of introduction

Carlton (1985) pointed out that the date of first collection is not necessarily, and indeed rarely is, coincident with the date of introduction. For a number of species, introduction dates are therefore approximate. The discovery of introductions could be related to the distribution and activities of collectors around the coast, especially those based at marine stations etc.

Boudouresque (1994) showed that the number of introductions to Europe, and specifically to the Mediterranean (excluding Leseppsian immigrants from the Red Sea via the Suez Canal), has

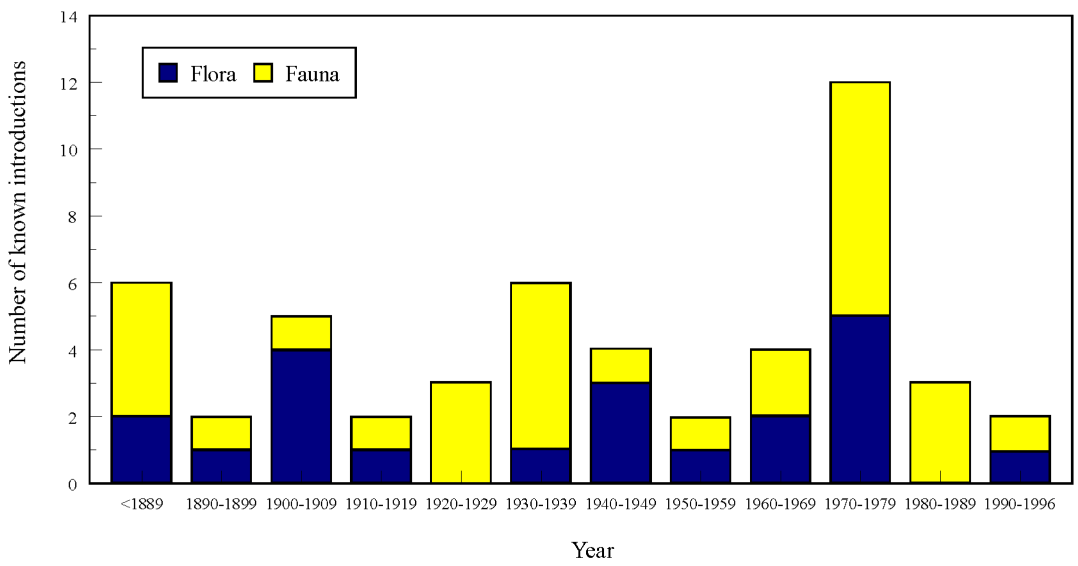


Figure 2. Numbers of reported non-native marine flora and fauna introduced to British waters in recent times.

steadily increased with time, particularly since the turn of the century. Similarly, in the Great Lakes in North America (International Council for the Exploration of the Sea 1993 - Appendix III, p. 69) the number of introductions has increased with time, the report does not state how many of those introduced subsequently became established.

The number of non-native species which have been introduced to British waters each decade over the past century are given in Figure 2. There seem to have been many introductions recorded in the 1970s which subsequently became established, but on the whole there is no discernible trend. This probably reflects the fact that only established introductions, as opposed to all introductions, are being considered.

2.3. Origin of non-native marine species in Britain

Species can be introduced directly from their point of natural origin, or secondarily from locations which they have colonised as non-natives. The probable sources, which do not always equate with natural range, of non-native marine algae and invertebrates found in British waters are shown in Figures 3 and 4. It has previously been observed that most successful introductions originate in similar latitudes (Carlton 1985; Hutchings, van der Velde & Keable 1987). For the non-native marine species in British waters it is clear from Figures 3 and 4 that they have come from similar latitudes, in particular from the east coast of the USA (especially the fauna) and from the western Pacific (especially the flora).

No non-native marine species were identified as originating from Africa in the current study. Species originating in Australia and New Zealand have generally been introduced directly rather than as secondary introductions and may reflect major shipping routes. One South American species, the spirorbid *Janua brasiliensis*, was introduced directly from its natural range. Secondary introduction from mainland Europe, as shown in Figure 5, is quite a common route of entry. Furthermore, several species, including *Corophium sextonae*, *Styela clava* and *Asparagopsis armata*, have reached Ireland following introduction to Great Britain (see Part 2 for details). The origins of seven non-native marine species listed are not known (the diatoms *Thalassiosira punctigera* and *T. tealata*; *Grateloupia doryphora*, *Clavopsella navis*, *Balanus amphitrite*, *Acartia tonsa* and *Rhithropanopeus harrisii*). Their distribution throughout the world is fairly varied so it is not known whether they have been introduced directly from their natural origin or as a secondary introduction. Several more of the species covered in this report are only presumed to have been introduced from specific locations.

2.4. Methods of introduction

Large expanses of water such as, in the context of Britain, the English Channel, North Sea, Irish Sea and Atlantic Ocean present barriers to many, particularly littoral, species and prevent their natural movement. Temperature and, for benthic species, the type of substratum are also considered to be barriers to the spread of species between geographic regions. These barriers can be bridged through the variety of methods which involve the intervention of man.

There are a number of known methods for the introduction of marine species:

- deliberate commercial introductions (including escapes from aquariums and the discard or release back into the sea of bait and edible species);
- associated unintentional introductions (with deliberate introductions);
- transport on ships' hulls (and on flying boats) either of sessile (fouling), boring or vagile (clinging) species (Zibrowius 1991);
- transport with ships' ballast, especially ballast water;
- movement through seawater canals linking biogeographically distinct water bodies.

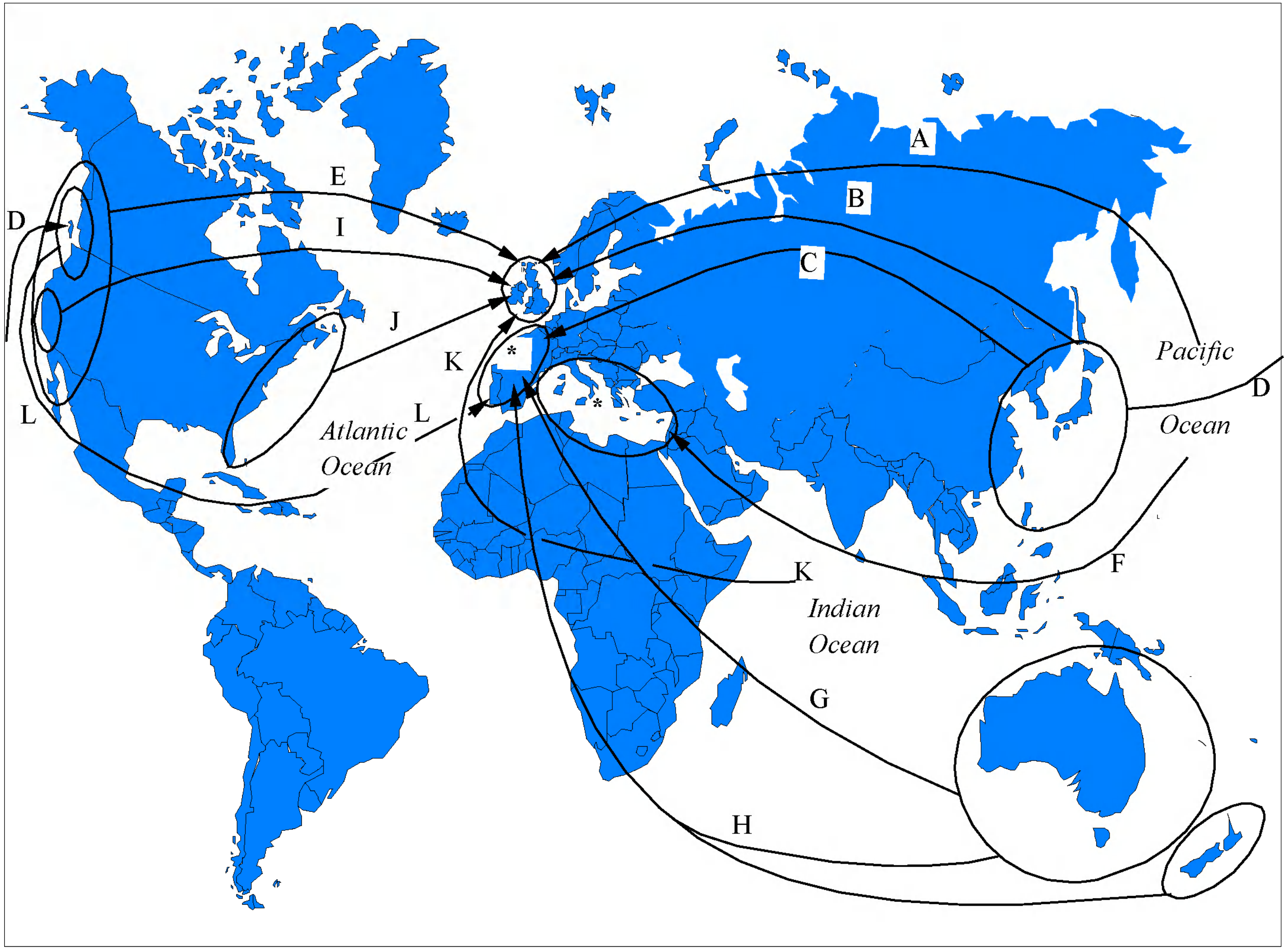
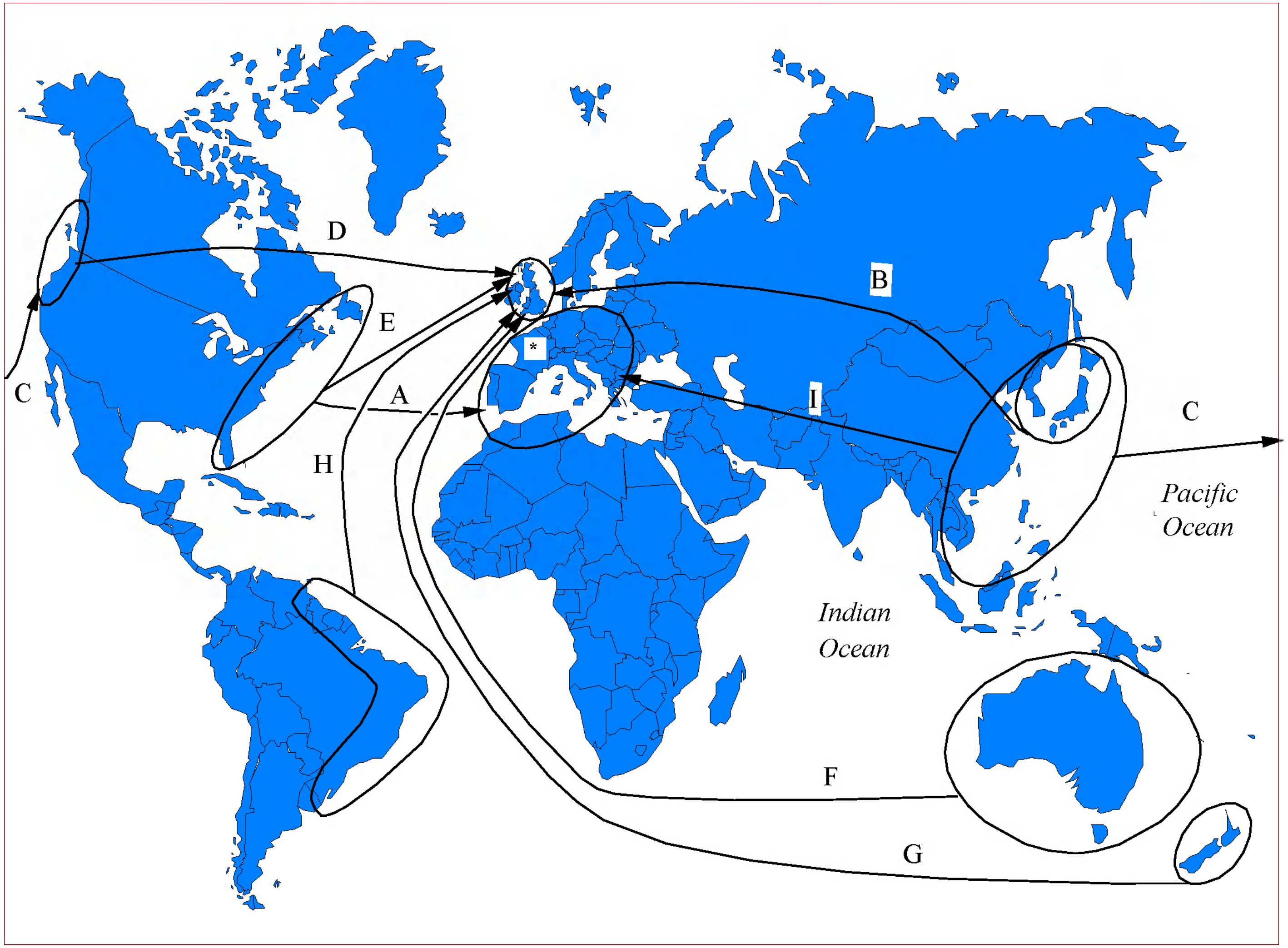


Figure 3. Probable sources (indicated by capital letters) of non-native marine flora in British waters. Arrows are not indicative of the actual route of introduction. Species from each probable source are listed to the right of the map. * (see figure 5).

A
Coscinodiscus wailesii
Agardhiella subulata
B
Bonnemaisonia hamifera
Codium fragile subsp. *atlanticum*
C
Grateloupia filicina var. *luxurians*
Sargassum muticum
Polysiphonia harveyi
Codium fragile subsp. *tomentosoides*
Undaria pinnatifida
D
Sargassum muticum
E
Colpomenia peregrina
F
Antithamnionella spirographidis
Undaria pinnatifida
G
Antithamnionella ternifolia
H
Asparagopsis armata
I
Pikea californica
J
Spartina anglica
Agardhiella subulata
K
Pleurosigma simonsenii
Coscinodiscus wailesii
Odontella sinensis
L
Sargassum muticum



A
Ensis americanus

B
Haliplanella lineata
Hydroides ezoensis
Pileolaria berkeleyana
Ammothea hilgendorfi
Styela clava

C & D
Crassostrea gigas

E
Goniadella gracilis
Marenzelleria viridis
Clymenella torquata
Hydroides dianthus
Eusarsiella zostericola
Crepidula fornicata
Urosalpinx cinerea
Crassostrea gigas
Mercenaria mercenaria
Petricola pholadiformis
Mya arenaria

F
Ficopomatus enigmaticus
Potamopyrgus antipodarum
Elminius modestus

G
Elminius modestus
Corophium sextonae
Tiostrea lutaria

Figure 4. Probable sources (indicated by capital letters) of non-native marine fauna found in British waters. Arrows are not indicative of the actual route of introduction. Species from each probable source are listed to the right of the map. * (see figure 5).

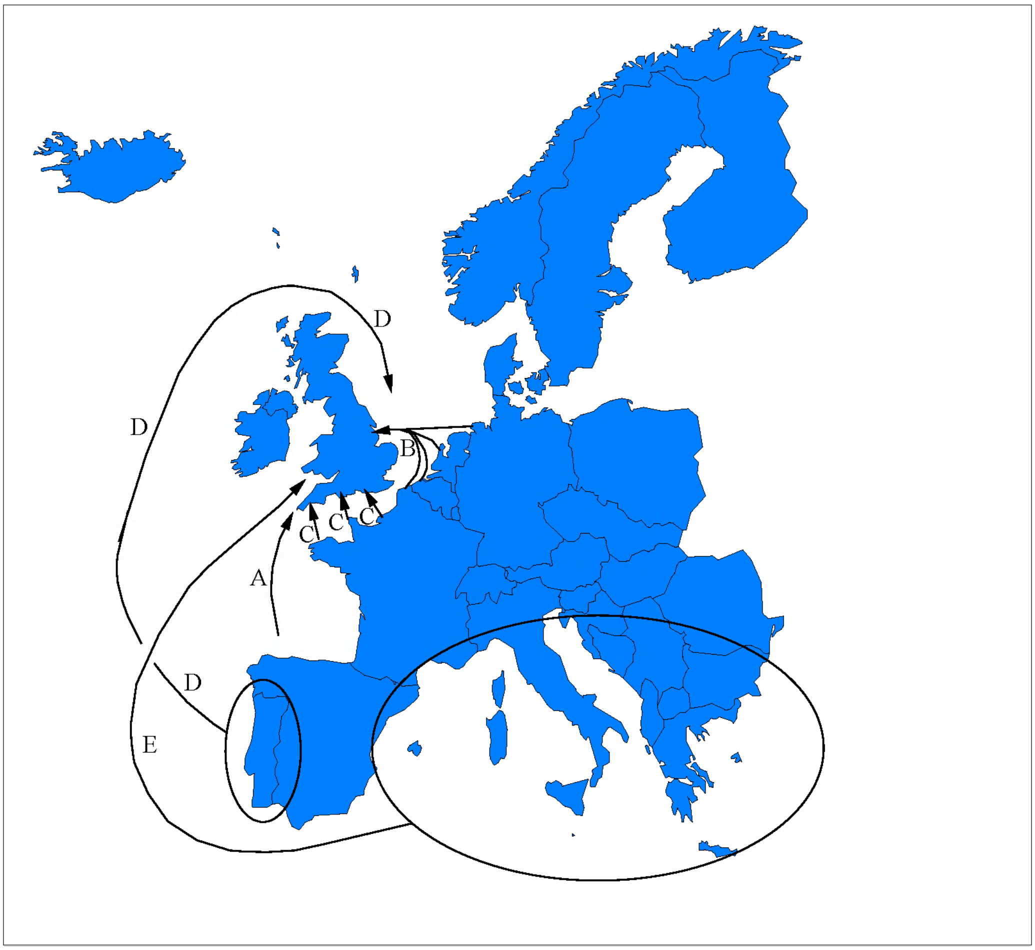


Figure 5. Likely routes of transfer of non-native marine flora and fauna between general areas of mainland Europe and Britain. Arrows are not necessarily indicative of the actual routes of introduction. Species involved in each route are:

A

Asparagopsis armata

B

Eriocheir sinensis
Codium fragile subsp. *tomentosoides*
Anguillicola crassus
Ensis americanus

C

Solieria chordalis
Polysiphonia harveyi
Asparagopsis armata
Sargassum muticum
Colpomenia peregrina
Undaria pinnatifida

D

Gonionemus vertens

E

Antithamnion spirographidis

Carlton (1992a) and Hutchings, van der Velde & Keable (1987) also suggested:

- release of species deliberately or unintentionally by scientists with scientific collections or attached to equipment;
- transport in the wood of packing crates;
- attached to drilling platforms that provide 'stepping stones' for hard substratum spp.;

- transport in ships' sea water intake pipes;
- transport on wet fishing nets.

Seaweed is also used as packing to keep marine animals cool and damp. (Indeed, *Sargassum muticum* came into northern France with oyster spat; and bait organisms are also often transported wrapped in seaweed.)

If species arrive through 'natural' means of distribution they are not considered as introductions, unless they have arrived following introduction to neighbouring countries. Natural methods can include drifting, rafting and transport on birds. However, the method of introduction is often not definitely known, only assumed through circumstantial evidence.

Deliberate commercial introductions can be for aquaculture including as food for edible species, for direct human consumption, for the pet and aquarium trade, as bait for use by anglers and as biocontrol organisms for pest control; other species can be brought in as unintentional introductions in association with any of these deliberate methods. Utting & Spencer (1992) gave an account of introductions of marine bivalve molluscs into the UK for commercial culture and detailed the species that arrived with them.

Transport on ships has been possible for millennia and, more recently, flying boats have been suggested. There have, however, been a number of changes over the years which will have affected the transport of species. Transport of solid ballast has been replaced by water, although sediment is often present in ballast tanks (which allows for the spread of cysts of diatoms and dinoflagellates). A lower proportion of vessels are made of wood nowadays and the movement of boring species is confined to transport associated with wooden-hulled vessels. Historically, major (European) ports were some distance from the coast, sometimes 30 - 40 miles from the open sea and therefore in waters of reduced salinity. In the 1970s there was a rapid move to container transport by large vessels which were restricted to coastal (high salinity) ports, e.g.

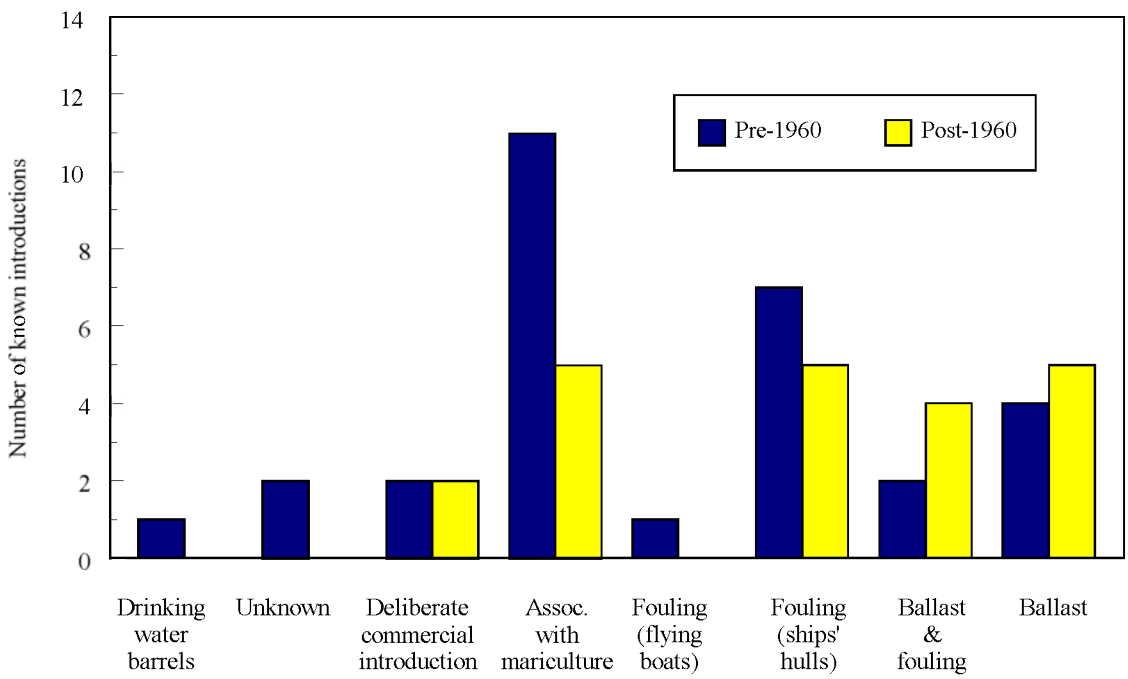


Figure 6. Comparison of methods of introduction of non-native marine flora and fauna introduced to British waters pre- and post-1960.

Felixstowe and Rotterdam. This change in practice may have accounted for an increased number of introductions (see Figures 2 & 6) and enhanced survival when ballast is discharged. The amount of transoceanic shipping has increased greatly, and a tendency of modern vessels to move faster through the water may increase the survival of both fouling species and those carried in ballast. (Indeed, Crisp (1958) suggested this as a factor influencing the transport of *Elminius modestus*). However, the increased use of anti-fouling paints this century has favoured present day transport of species in ballast tanks rather than on hulls. Carlton (1992 a & b) considered that ballast water probably provides the greatest flow of neritic species globally in modern times.

It is noteworthy that numerous phytoplanktonic organisms have been recorded in ballast water in vessels entering the Baltic and North Seas (Anon. 1994a).

Transport on ships' hulls by fouling and clinging requires certain characteristics of the species. Furthermore, it may be considered that those species preferentially distributed on ships' hulls have had ample opportunity to spread, especially as some are now cosmopolitan in occurrence, such as certain serpulids. Conversely, ballast water is the least selective means of transportation of species from the ecological and taxonomic viewpoint (Carlton & Geller 1993). However, it is probably the most feasible method of transport for planktonic organisms. Over a quarter of non-native marine species in British waters may have been introduced with ballast, either in ballast water or in sediments transported in ballast tanks, which makes this a significant method of introduction. It is interesting to note that only a single marine macroalga of a total of sixteen non-natives identified may have entered by this method. Yet all the phytoplanktonic introductions are considered to have entered with ballast (Wallentius in press).

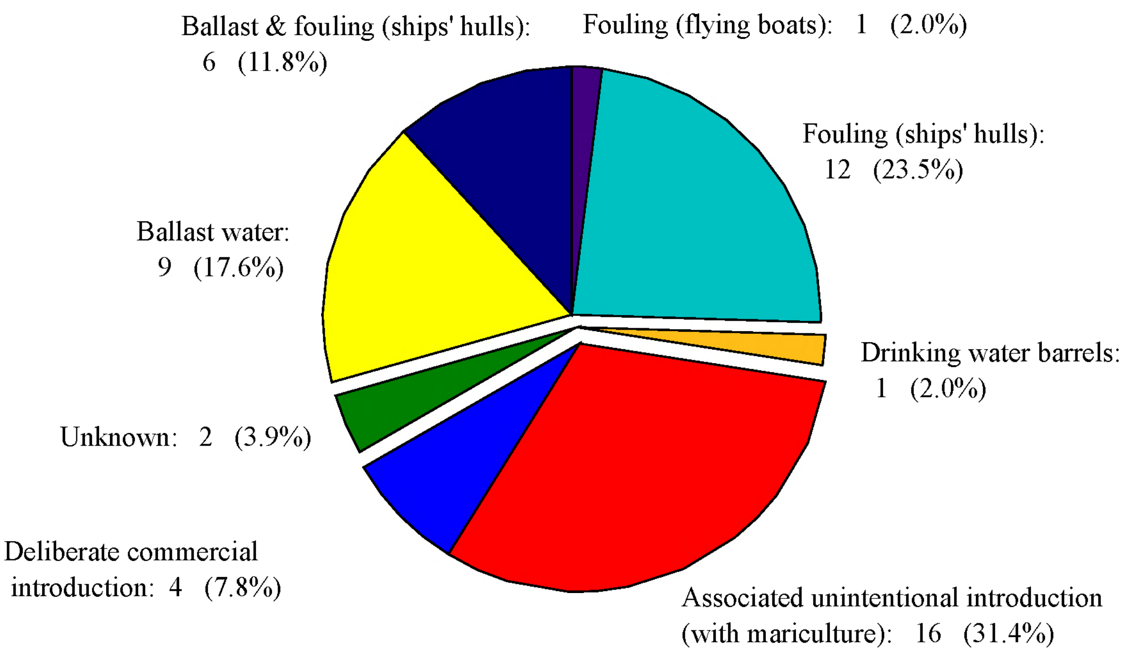


Figure 7. Probable primary methods of introduction of non-native marine flora and fauna found in British waters. Numerals indicate number of species involved, and the percentage of total introductions.

Prior to 1960 there were substantial introductions of marine species in association with imports for aquaculture. However, quarantine regulations since that time have halted this method of entry to the UK.

The range and relative importance of different methods of introduction of non-native marine species into British waters, where known, is shown in Figure 7. It indicates that over half of all non-natives were probably introduced in association with shipping.

The most common method of introduction of non-native marine algae has been unintentional in association with deliberate commercial introductions, particularly of oysters (from Japan and North America). Several faunal species have also been introduced unintentionally as associated species, particularly with oysters (Duggan 1979; Elton 1958). The majority of introduced invertebrates have arrived in association with shipping either as fouling or in ballast water, and it appears that the former association is more common (especially for tube-dwelling polychaetes). A number of fish species have been introduced and escaped into the wild but have not become established in British waters (see Table 2). In Great Britain no marine species are known to have become established in the wild following escape from public aquaria (unlike the alga *Caulerpa taxifolia* released from the Monaco aquarium into the Mediterranean Sea). It is not known whether unintentional release from marine laboratories has resulted in any introductions which have subsequently become established: none has been reported. It appears that, of deliberately introduced invertebrates, only bivalve molluscs have subsequently become established.

2.5. Reasons for successful establishment

Ribera & Boudouresque (1995) considered that the success of an introduction relies as much on the biological characteristics of the species as on the host environment. Therefore, they considered one essential factor for success was the availability of vacant niches and another was the low biological diversity of the host community (e.g. as found in harbours).

Carriker (1992) did not consider that biological (morphological, physiological, reproductive, genetic, behavioural, etc.) characteristics of successful invaders can be identified with any degree of reliability. Nonetheless, Ehrlich (1986) suggested the following possible attributes of potentially successful terrestrial invaders: abundance (implying success) in the native habitat, polyphagous (adaptable diet), short reproductive cycles, high genetic variability, ability of fertilised females to colonise alone, larger size than most relatives, association with man and ability to function well in a wide range of physical-chemical environmental conditions.

Carriker (1992) stated that successful geographical dispersal is the product of an interaction between physiological properties of the organism and the quality of the environment. Estuarine species, though broadly tolerant of a widely fluctuating complex of ecological factors, only rarely invade oceanic habitats, and conversely, successful invasions in the reverse direction are also rare. On the other hand, successful invasion by estuarine species into other brackish waters, especially at a similar latitude, is common (with some of the most recent marine introductions to Britain (e.g. *Rhithropanopeus harrisii* and *Mytilopsis leucophaeta*) being brackish water species).

The data show that the most common individual reasons for success of non-natives in British waters are favourable physical factors including a favourable temperature range, often elevated sea water temperatures in relation to regional or local conditions. A high reproductive rate of the species concerned is also a contributing factor. Warm-water species, which include most of the introduced shellfish, may breed only under conditions of elevated water temperatures. However, it is not only absolute temperature which influences their success but the general cumulative influence of elevated temperatures over an appropriate period (Mann 1979). In addition, it appears that physiological adaptation may improve the reproductive success and hence the establishment potential of some species, e.g. the American hard-shelled clam *Mercenaria mercenaria* in Southampton Water (Mitchell 1974, 1976).

Overall, a combination of several factors is responsible for the success of most non-native species in British waters. Lack of predators, the availability of unfilled niches, presence of suitable food and general hardiness of the species concerned are factors that have been identified as responsible for success of introductions. A few species showed limited success in establishment, not having spread much beyond the immediate area of introduction (also see the following section examining the rate of spread). For about a quarter of the species considered the reasons for their success are unknown.

2.6. Rate of spread

There are four successive phases in the introduction of a species: arrival, settlement, expansion and persistence (Mollison 1986). If a species successfully achieves settlement, whether straight away or through successive inoculations, it will try to expand to occupy the whole of the biotope(s) and the geographic range to which it may have access (Ribera & Boudouresque 1995). The dispersal of a species can be marginal, involving natural means e.g. through pelagic larval dispersal, or remote, with human assistance, e.g. through adult transport on ships' hulls (Crisp 1958). The information gathered in the present study relates to the rate of geographic spread by whatever method, as details of the density of cover are often absent.

The rate of spread of non-native species in British waters varies according to the species. Those which spread very rapidly are generally termed 'invasive', a term which may also imply dominance. An analysis of the rate of spread of non-native marine species in British waters (or in nearby waters where information for Britain is lacking) is given in Table 3.

Ten out of the 22 plant species identified spread fairly rapidly, as indicated in Table 3. Non-native marine invertebrates spread more slowly than marine non-native plants, and nine (out of 31) had not spread (see Table 3).

2.7. Methods and factors influencing spread, and distribution

The methods involved in spread were found to be generally the same as the methods involved in the introduction of species to British waters. Where there has not been any spread outside the area to which a species was originally introduced, local colonisation occurs by reproductive means. Some species of alga were introduced with man's assistance but then spread around Britain or Europe by rafting or floating, e.g. *Sargassum muticum*. On the whole the factors presented as reasons for the success of the species are the same as those influencing the extent of its spread, for instance, elevated water temperatures probably account both for the success, in terms of becoming established, of *Janua brasiliensis* as well as its distribution being restricted to Portsmouth Harbour in the Solent.

There were no common patterns discerned in the distribution of the species. However, there are far more introduced species on the south and west coasts of Britain. There are also areas which seem to abound with non-natives, e.g. the Solent (Farnham 1980; Zibrowius & Thorp 1989), probably as a result of the large volume and history of shipping in the area; and the Essex coast, in connection with oyster grounds and associated unintentional introductions (Utting & Spencer 1992). A survey of the southern part of Poole Harbour in the early 1980s revealed that non-native species represented 60% of the wet weight of all species present (Dr Peter Dyrynda pers. comm.).

Table 3. Rate of spread of non-native marine taxa in British waters.

Rate of spread	No. of plants	No. of invertebrates	Total no. of species
Restricted to locality where first introduced	1	7	8
very slow	2	4	6
slow	3	5	8
moderate	5	6	11
rapid	7	5	12
very rapid	3	1	4
unknown	0	2	2
Total	21	30	51

The terms used to describe the rate of spread are fairly loose in their application, but can broadly be interpreted as:

restricted	no spread beyond a few kilometres from point of introduction;
very slow	no spread beyond local district (up to 30 kilometres) within 30 years;
slow	limited spread (up to 150 kilometres) since introduction or within 30 years;
moderate	regional spread (beyond 150 kilometres) within present country since introduction and / or spread to neighbouring countries within 30 years;
rapid	spread throughout much of the British Isles in 50 years and / or to neighbouring countries within 10 years;
very rapid	spread throughout much of the British Isles in 50 years or less and to neighbouring countries within 5 years.

3. Effects of non-native species and their practical control

3.1. Effects on the environment

Rosenthal (1980) considered categories of detrimental effects of an introduced species, including the following ecological effects:

- population explosion of the introduced species, leading to competition with and eventual elimination of native species;
- concomitant introduction of new pests, diseases and parasites harmful to resident species.

Kohler & Courtenay (1986) categorised effects of introductions of aquatic organisms as follows:

- habitat alteration, including the presence of excessive weed, provision of new niches and changes in water quality;
- trophic alterations, including dietary competition and predation;
- spatial alteration, namely competition for space;
- gene pool deterioration through hybridisation;
- introduction of disease, which they considered poses the greatest threat to the native community of all effects listed.

The above points cover the majority of effects exerted by non-native marine species in British waters. Additionally the present study revealed associated effects from establishment, for instance, seabed damage from subsequent fishing of those commercially important introduced species; the effects of control methods on non-target species; and fouling of other species. The actual and potential effects of non-native marine species in British waters are summarised in Tables 4 & 5 - see Part 2 (directory of species) for full details.

The only effect which non-native algae in British waters imposed on the ecosystem seemed to be the physical displacement of native species. Fortunately, the smothering, toxic, circumtropical alga *Caulerpa taxifolia* which is non-native in the Mediterranean, posing a tremendous threat to wildlife, is not considered likely to invade northern European waters.

Non-native invertebrates have been found to exert a range of effects, of which the most common was displacement of other species. Indeed, any animal species of significant proportions and / or population densities may compete for food and space with native species, sometimes in the planktonic larval phase, e.g. *Elminius* versus *Balanus* and *Chthalamus*.

Fisheries for established non-natives can have adverse effects on the ecosystem due to the destructive nature of the fishing gear used. It is expected that if the species became established in large enough densities, a fishery for the razor shell *Ensis americanus* could also pose problems on account of the potentially damaging harvesting methods (Hall, Basford & Robertson 1990).

Not all effects exerted on the environment by non-native species are detrimental, as shown in Table 5. They can also help improve water quality and provide a food source for native wildlife.

Some species have caused other effects where introduced in countries other than Great Britain, and these effects may not yet be seen in Britain, as listed in Table 4.

Table 4a. The actual and potential effects of non-native marine plants introduced to Britain.

Phylum	Species	Probable method of introduction	Effects on the environment and commercial interests
Bacillariophyta	*Pleurosigma simonsenii*	In ballast	Displacement of native species, sometimes to the point of dominating as a bloom.
	Odontella sinensis	In ballast	It is a prominent contributor to the winter and spring phytoplankton of the western English Channel.
	Coscinodiscus wailesii	In ballast	*C. wailesii* can produce copious mucilage resulting in heavy grey slime which can clog fishing gear and cause dermititis to fishermen.
Rhodophyta	*Grateloupia filicina* var. *luxurians*	Accidental with oysters	On account of its potential large size it may be capable of displacing other species.
	Polysiphonia harveyi	Accidental with oysters	*Polysiphonia harveyi* possibly displaces native species as it can become very abundant, despite its small size.
Chromophyta	*Colpomenia peregrina*	Accidental with oysters	When growing attached to oysters it can float off with them when the air-filled thalli grow large enough, hence its name 'oyster thief'. Not a current problem in GB.
	Undaria pinnatifida	Deliberate to France but secondarily on hulls	*Undaria* may possibly displace native species and it is a fouling agent. In France it is commercially cultured for food.
	Sargassum muticum	With oysters to France but secondarily by rafting	In Britain *Sargassum* can physically displace the native species *Zostera marina* (by shading out underlying eel-grass growth) and also *Halidrys siliquosa*; *Cystoseira* spp. and *Padina* may be affected in large, intertidal pools. It is a pest and fouling organism; it interferes with navigation particularly when detached and floating in large masses; it blocks propellers and intakes in small boats; and it can be a fouling organism on oyster beds and fouls the nets of commercial fishermen.
Chlorophyta	*Codium fragile* subsp. *tomentosoides* & subsp. *atlanticum*	With aquaculture species elsewhere in Europe and possibly by rafting secondarily	Physical displacement of the native species *Codium tomentosum*.
Plantae	*Spartina anglica*	In ballast	Rapid colonisation of *Spartina anglica* over sites with large wintering populations of waders and wildfowl reduces habitat availability for feeding and roosting. Displacement of the native *S. maritima* has altered the course of succession, producing a monoculture of low intrinsic value. Amenity interests may also be affected.

Table 4b. The actual and potential effects of non-native marine invertebrates introduced to Britain.

Phylum	Species	Probable method of introduction	Effects on the environment and commercial interests
Nematoda	*Anguillicola crassus*	With infected eels	Common eels *Anguilla anguilla*, if infected by the nematode, show increased mortality at high infestation levels.
Annelida	*Hydroides ezoensis*	In ballast or on ships' hulls	This species is a severe fouling organism on harbour structures and ships' hulls throughout Southampton Water, adding considerably to fouling of poorly protected ships and causing buoyancy problems to buoys. It provides food for fish predators, and the massive encrustations can provide shelter to a variety of small species.
	Janua brasiliensis	On ships' hulls	In the Goes Canal in the Eastern Scheldt, The Netherlands, the dense settlements of *J. brasiliensis* on the eel grass *Zostera* weighed down leaves onto the canal sediment, thus impairing the *Zostera*'s photosynthetic efficiency; this has not been studied in Britain.
	Hydroides dianthus	On ships' hulls	*Hydroides dianthus* is a fouling organism. In its native eastern North America it can kill young American oysters *Crassostrea virginica* by over-growing them.
	Ficopomatus enigmaticus	On ships' hulls	Large numbers of *Ficopomatus* in enclosed waters can have very beneficial effects on water quality, reducing suspended particulate loads and making it less eutrophic through improving the oxygen and nutrient status. It is also a fouling species.
	Marenzelleria viridis	In ballast	In the Tay estuary *M. viridis* has been inversely related to other benthic species. In the Ems estuary in The Netherlands it specifically competes with *Hediste diversicolor*. It is preyed upon by fish.
Crustacea	*Eriocheir sinensis*	In ballast	In Germany, breeding aggregations of *E. sinersis* migrate seawards and through their burrowing activity may damage estuarine banks. They have caused damage to the nets of eel fishermen in Britain.
	Balanus amphitrite	In ballast or on ships' hulls	It is a fouling organism of ships, buoys and harbour structures.
	Elminius modestus	On ships' hulls	*Elminius modestus* competes with *Semibalanus balanoides* in northern areas, *Chthamalus* species in southern Europe and *Balanus improvisus* on the south coast of Britain. It is a fouling organism in favourable conditions.

Mollusca	*Crepidula fornicata*	Accidental with oysters	*Crepidula* competes with other filter-feeding invertebrates and encourages deposition of mud; for these reasons it is a pest on commercial oyster beds where it also renders the substratum unsuitable for the settlement of spat.
	Urosalpinx cinerea	Accidental with oysters	*Urosalpinx* predates native oysters and devastates commercial oyster beds through predation.
	Crassostrea gigas	Deliberate	Commercially important. In N. America it can settle in dense aggregations, excluding other intertidal species.
	Ensis americanus	In ballast	*Ensis americanus* is fished in some parts of continental Europe.
	Mercenaria mercenaria	Deliberate	May displace *Mya arenaria*. Digging and dredging for this clam significantly affects the environment, particularly *Zostera* beds. The Solent fishery declined due to poor spatfall, and possibly due to stock depletion and habitat damage.
	Petricola pholadiformis	Accidental with oysters	In Belgium and The Netherlands it has almost replaced the native white piddock *Pholas candida*, but no displacement of species has occurred in Britain.
Chordata	*Styela clava*	On ships' hulls	Serious competition for food results from large populations. It is a fouling pest on ships' hulls and oyster beds.

3.2. Effects on commercial interests and beneficial effects

The actual and potential effects of non-native marine species on commercial interests identified from the current study are summarised, together with examples of species which exhibit such effects, in Table 5. Commercial uses which some non-native marine species in Britain are put to elsewhere in the world are listed in Table 6.

Fouling species which are a potential problem are listed in Table 4. A few species, namely *Polysiphonia harveyi*, *Haliplanella lineata*, *Janua brasiliensis*, *Antithamnionella ternifolia* and *Antithamnionella spirographidis*, are fouling organisms but have negligible effect, mainly on account of their small size.

Other than the supply of a new source of exploitable species, the effects of non-native marine species on aquaculture are either negligible or detrimental. Host-specific damage is caused by predatory and parasitic species. Such undesirable species generally arrive in association with the intentional introductions. There are other aquaculture pests which can literally smother the culture species or adversely change the habitat it lives in.

Deliberate introductions can occasionally cause unexpected problems. The success of king crabs transplanted into the Barents Sea from the Russian Far East in the 1960s had by 1994 resulted in problems for gill-net fishermen as crabs destroyed their nets. In the worst cases this forced them to quit gill-net fishing on their regular grounds (Anon. 1994b). On occasion, non-native species have also caused damage to nets of British fishermen.

Table 5. Effects of marine non-native species in British waters on the environment, nature conservation interests and commercial interests.

Effects on environment, nature conservation and commercial interests	Examples
Displacement of native species	*Elminius modestus, Sargassum muticum, Styela clava, Crepidula fornicata*
Introduction of new pests and parasites which affect native species	*Crepidula fornicata, Anguillicola crassus*
Habitat alteration	*Crepidula fornicata, Spartina anglica*
Changes in food webs, particularly through dietary competition and predation	Most faunal species
Degradation of integrity of gene pool through hybridisation	*Spartina anglica*
Associated effect of commercial harvesting	*Mercenaria mercenaria*
Improved water quality	*Ficopomatus enigmaticus*
Fouling of ships, marinas, moorings, nets, shellfish & aquaculture structures	*Sargassum muticum, Balanus amphitrite, Styela clava*
Competition with and predation on aquaculture sp.	*Crepidula fornicata, Urosalpinx cinerea*
Food source to humans and wildlife	*Crassostrea gigas, Mercenaria mercenaria*
Damage to nets	*Coscinodiscus wailesii, Eriocheir sinensis*
Increased productivity of previously uncolonised habitats	*Sargassum muticum* is a primary coloniser.

Table 6. Commercial uses applied elsewhere in the world to some non-native marine species found in Britain.

Species	Commercial uses of species elsewhere in the world
Solieria chordalis	This species can be used for the production of agar.
Grateloupia filicina var. *luxurians*	This species is used in the western Pacific as a food and as a raw material in the extraction of carrageenan.
Grateloupia doryphora	This species is used in the Pacific as a food and as a raw material in the extraction of carrageenan.
Codium fragile subsp. *atlanticum & tomentosoides*	Both subspecies are a food source in the Far East.
Tiostrea lutaria	A commercially important species in New Zealand but only kept for experimental purposes in Britain.
Mya arenaria	In the USA this species is considered a delicacy and is used for "clam-bakes" at the beach, but not in Britain.

A number of beneficial effects attributable to non-native marine species have been identified. These include: food source for humans and wildlife, raw materials for the alginate industry, improvements in water quality, due to increased filtration, culch (a favourable substratum) for oysters and increased productivity of previously uncolonised habitats. Examples of species having such effects are listed in Tables 5 and 6.

3.3. Control methods and effectiveness

In Britain, a variety of physical, chemical and biological control measures have only been employed on species which are a nuisance, such as the Jap weed *Sargassum muticum*, the leathery sea squirt *Styela clava* and the slipper limpet *Crepidula fornicata*. The effectiveness of the methods has varied, although no non-native marine species has ever been eradicated from British waters using a directed approach. Some introduced species have, however, become extinct in Britain through external factors, e.g. the closure of a power station.

A variety of species, listed under the section on the effects on commercial interests, are fouling organisms and need to be removed. Their control is effected by scraping of buoys and ships' hulls. The application of anti-fouling paints limits their ability to settle but these paints themselves have an environmental impact.

The American whelk tingle *Urosalpinx cinerea* underwent a dramatic decline in Essex estuaries as a result of imposex caused by tributyltin (Gibbs, Spencer & Pascoe 1991). This antifoulant also affected native species, particularly the closely related dog whelk *Nucella lapillus*.

4. International control of transfers of marine organisms

4.1. Statutory and voluntary measures on the introduction of non-indigenous marine species

Provisions which cover marine introductions appear in several global treaties as well as in an increasing number of regional conventions. However, there is no law which imposes a total prohibition in this field (De Klemm 1994). The usual method is that introductions become subject to a permit requirement, which is usually embodied in national legislation.

The most recent and far-reaching international convention covering this subject is the Convention on Biological Diversity of 5 June 1992 that requires its Contracting Parties, as far as possible and appropriate, *"to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".* This Convention also addresses liability for damage caused by introductions where insufficient or ineffective measures have been taken to eradicate them once released. The United Nations Law of the Sea which came into force in 1994 also makes provision for the control of introduced marine species but the United Kingdom is not a signatory. The Bonn Convention for the Conservation of Migratory Species of Wild Animals stipulates provision for *"the protection of (the) habitats (of migratory species) from disturbances, including strict control of the introduction of, or control of already introduced, exotic species detrimental to the migratory species".*

Relevant regional conservation instruments apply to the UK with respect to introductions. The Berne Convention on the Conservation of European Wildlife and Natural Habitats requires "*each Contracting Party to strictly control the introduction of non-native species*". The EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora obliges Member States to ensure that the deliberate introduction to the wild of non-native species is regulated so as not to prejudice natural habitats and species. The EC Fish Health Directive indicates that it shall not prejudice the implementation of national legislation directed at the preservation of species despite its primary aim being to facilitate trade in live fish.

The Wildlife and Countryside Act 1981, which applies to the waters around Great Britain, states that it is an offence to release (or allow to escape) into the wild any kind of non-native animal, except under licence. In addition, an introduced species of animal, once it is established in the wild, and any plant, established or not, known to have detrimental effects on the environment, may be listed on Schedule 9 of the Wildlife and Countryside Act 1981. It is illegal to release or allow to escape into the wild any species so listed.

Recommended procedures and practices to diminish the risks of detrimental effects from the intentional introductions and transfers of marine (including brackish water) organisms are described in the 1994 International Council for the Exploration of the Sea Code of Practice (ICES 1994). This Code of Practice represents an international policy as agreed in the north Atlantic and is aimed at persons engaged in activities that could lead to intentional or accidental release of introduced species.

The International Maritime Organisation (IMO) has developed voluntary guidelines that call upon ships' operators to take care when loading ballast water and to avoid areas where there have been known occurrences of water-borne diseases, algal blooms, or dangerous organisms and concludes that "*in the absence of more positive means of control, exchange of ballast water in deep sea areas offers the most reasonable and cost effective means*" of control.

4.2. Concerns and scope for future measures

Populations of introduced species, sometimes large populations, can go un-noticed for a number of years. For example, the polychaete worm *Hydroides ezoensis* was accidentally collected in Britain by a research student gathering fouling diatoms. These massive encrustations might not have otherwise been brought to light.

With all introduced species initial detection relies upon the presence of expertise to recognise the unusual nature of the species, so there is often a time lag between the arrival and detection of an introduction. Furthermore, after the initial swell of interest, very little time and effort is put into monitoring the survival and spread of an introduced species. As a result there are very few data available with regard to the period of survival of populations of introduced species.

In the interests of gaining and maintaining an accurate picture of the presence, abundance and spread of non-native marine species, routine investigation of ports, harbours, marinas and estuarine habitats should be encouraged. Further areas in which research needs to be developed are expounded by Carlton (1996b); namely, the ecology, biogeography, prevention and control of introduced species.

The environmental factors to which an introduced species is subject in British waters are likely to be quite different from those it experiences in its natural range, and may contribute to its success and possibly invasiveness. For instance, two of the non-natives described, the Jap weed *Sargassum muticum* and the polychaete worm *Clymenella torquata* are reported to grow much larger in Britain than in their countries of origin possibly as a consequence of differing environmental conditions. However, many introduced species that proliferate and cause environmental imbalance have been responsible for no such problems in their native regions (Ribera & Boudouresque 1995). These factors make the prior identification of potential invaders more difficult.

On the whole very few introduced marine species become established in British waters, and of those which do, only a small proportion prove to be a nuisance to sea users or a threat to the environment. Ribera & Boudouresque (1995) stated that, in general, 80% of introduced species have no effect on the indigenous community.

Unfortunately, the effects of non-natives can sometimes be environmentally and economically disastrous (Carlton 1996b). The effects are compounded by activities associated with their presence. Where a species is commercially important and present in sufficient numbers, it may be exploited and, depending upon the method of collection or intensity of cultivation, may have impact upon the nature conservation interests of an area. The control of species which become a nuisance can have quite far reaching effects. For instance, mechanical removal or use of pesticides on a non-native would almost certainly affect non-target species. Activities associated with introducing commercial species, for instance preparing the ground or installing culture equipment, also have an important effect.

Some areas are reported to have high proportions of non-native species, as documented earlier, where the biomass is composed of more introduced than native species. This has severe implications for the nature conservation integrity of communities and for species being displaced by non-natives. The risk of such situations developing makes it imperative that measures are taken to minimise the likelihood of introductions to areas of nature conservation importance.

The potential effect of an introduction is hard to predict and control methods are generally ineffective. Indeed, no non-native has successfully been eradicated from British waters. The only way of preventing detrimental effects from occurring as a result of non-native introductions is to ensure they do not gain entry in the first place.

Quarantine regulations since the 1960s and the Molluscan Shellfish (Control of Deposit) Order 1965 have ensured that introductions to Britain resulting from aquaculture have been minimised. It is of some concern that recent legislative changes in connection with the formation of the European Single Market under the Fish Health Directive 91/67/EEC has led to a slackening of these controls. Indeed, better measures for reviewing and licensing the introduction and movement of species which are not native to Great Britain may be required.

The implications for nature conservation of, for example, non-native shellfish deposits would be potentially the most serious in areas of high marine nature conservation interest, but likely effects would depend on the physical, chemical and biological characteristics of the site and the likelihood of conditions (for instance elevated seawater temperatures) encouraging reproduction and successful establishment of wild populations.

It appears that discharge of ballast water is probably the most common method of introduction of marine and brackish-water species on a global scale. Certain countries have developed particular interest in this topic as a result of immense economic damage caused by introductions, for instance to the Great Lakes in North America. Currently the International Maritime Organisation is devising international control methods, but these are currently voluntary. ICES is also developing guidelines in relation to ballast water exchanges in the North Atlantic. It is important that sensible international measures are made mandatory to minimise the potential impacts of introductions through ballast water.

Managers, when considering the introduction of any foreign species, should seriously question why a local native species would not be adequate commercially, following the advice of Courtenay & Robins (1989) as it relates to fish.

Several introductions to Great Britain have almost certainly crossed the Channel between Britain and the rest of Europe. The avoidance of unwanted organisms being introduced to a country clearly needs to be addressed on a global and regional basis.

As escapes from captivity are inevitable, the safest solution to prevent the introduction of undesirable species is consequently to prohibit the import of all live introduced animals. Exception to this could be made for aquarium and edible species where it was certain that such animals would not survive in the wild if they were to escape due to exposure to lethal temperatures etc.

4.3. Legislative recommendations

(adapted from De Klemm 1994)

Harmful introductions can be considered as a self-regenerating form of pollution which may have irreversible effects on natural ecosystems and other species. These effects may be impossible or extremely costly to control once the introduced species has become established. Prevention is consequently of the utmost importance.

1. Any legislation should be based on the precautionary principle which is gradually becoming an accepted basis for the development of environmental law. This means that the rule of deliberate introductions should be that permits are in principle denied, unless it can be shown that there are at least good scientific reasons to believe that the proposed introduction will be harmless.
2. The ICES (and European Inland Fisheries Advisory Commission) Codes of Practice, which require the imposition of quarantine procedures, should be given legal force and become binding upon permit-issuing authorities. This could be achieved within the European Community by the adoption of a Regulation. For those States which are not members of the Community, it would be necessary to use other instruments, such as the Barcelona and Helsinki Conventions for the marine environment.
3. To prevent escapes from captivity or liberation by 'do gooders' etc. the implementation of the precautionary principle requires strict controls on imports of live specimens of those species which may survive in the European environment. Within the European Community, this would also require a Regulation. It might also be necessary to regulate intra-Community trade, although this could create difficulties as such restrictions would run counter to the basic objectives of the EC. Import controls should be accompanied by prohibitions or restrictions on the possession, sale and transport of exotic species.
4. Special precautions need to be taken to avoid accidental introductions into particularly sensitive areas, such as islands.

5. All legislation regulating the introduction of aquatic organisms should empower enforcement personnel to inspect premises and to seize and destroy specimens of introduced species which are illegally imported or possessed. This is hardly ever the case at present, although Western Australia is a notable exception.
6. An integrated holistic approach should be adopted. All these rules should be applicable to all species, whether terrestrial, freshwater or marine. As matters stand, where national legislation on introductions does exist, it almost always applies only to terrestrial or freshwater species and marine species are often completely ignored.
7. Where prevention has failed and an introduced species has become established, there is clearly a need to try to eradicate it as quickly as possible before it is too late.

5. Glossary

by Colin R. McLeod, Joint Nature Conservation Committee (from Hiscock 1996).

alien species A non-established introduction, i.e., a species introduced by human agency into a geographical region outside its natural range (q.v.), but which has not established self-maintaining or self-regenerating populations in the wild in the new area. See 'non-native'.

aquaculture The cultivation of aquatic organisms by human effort for commercial purposes. For the cultivation of marine organisms in seawater, the term 'mariculture' is also used (based on Baretta-Bekker, Duursma & Kuipers 1992).

biodiversity (biological diversity) "The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." (UN Convention on Biological Diversity, 1992.)

cryptogenic species A species which is not demonstrably native or introduced (Carlton 1996a).

fouling (biological) Growth of sessile algae and animals, especially on a ship's bottom or other artificial underwater structures, or in water-intake apparatus (based on Baretta-Bekker, Duursma & Kuipers 1992); also termed 'biofouling'.

geographic region With regard to biogeography and species distribution, a region which is separated from an adjacent region by a barrier which is usually impenetrable to many species, limiting their movement or preventing establishment outside their natural geographical range.

introduced species Any species introduced by human agency into a geographical region outside its natural range (q.v.). The term includes non-established ('alien') species (q.v.) and established non-natives (q.v.), but excludes hybrid taxa derived from introductions ('derivatives').

natural range The geographical range of a species in historical times (i.e. since the beginning of the Neolithic Age (*ca* 3,500 BC), prior to any changes to that range as a result of human agency.

non-established introductions Species that are introduced through the agency of man but have not become established and are incapable of establishing self-sustaining or self-propagating populations without deliberate intervention by man. (Also called 'alien species'.)

non-native (species) A species that has been introduced directly or indirectly by human agency (deliberately or otherwise) to an area where it has not occurred in historical times[2] and which is separate from, and lies outside, the area where natural range extension could be expected. The species has become established in the wild and has self-maintaining populations. The term also includes hybrid taxa derived from such introductions.

parasite An organism that lives in or on another living organism (the host), from which it obtains food and other requirements. The host does not benefit from the association and is usually harmed by it. cf. 'commensalism', 'symbiosis'.

recent colonist A species which, without any human intervention, has extended its natural geographical range (q.v.) in recent times and which has established new self-maintaining and self-regenerating populations in the wild. cf. 'non-native'; 'vagrant'.

re-introduction A species which has been re-introduced by human agency, deliberate or otherwise, to an area within its natural geographical range (q.v.) but where it had become extinct in historical times.

sessile Permanently attached to a substratum, at least in adult form.

substratum (pl. substrata) Surface available for colonisation by plants and animals; a more correct term in this context than 'substrate'.

vagile Clinging; sedentary (from Zibrowius 1991). cf. 'sessile'.

vagrant (species) Individuals of a species which, by natural means, move from one geographical region to another outside their usual range, or away from usual migratory routes, and which do not establish a self-maintaining, self-regenerating population in the new region. cf. 'alien species'; 'recent colonist'.

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[2] "In historical times" is taken as being since 5000 years before present.

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Annex 1. Questionnaire used for gathering information on non-native marine species.

JNCC study of introduced non-native marine species in Britain

The JNCC study aims to cover all introductions of marine fauna and flora (including parasites) to Britain. To do this we need to gather together key information on species from a wide range of individuals. If you are able to help, please give details for each species on the following, indicating other factors as appropriate (please photocopy the form and complete one per species). Any extra notes, particularly on environmental effects would be welcome:

Species

- main taxonomic group..
- generic and specific name..
- common name...

Origin (indicate if possible)

- date of introduction...
- natural origin (continent and country)..
- introduced from (continent and country)..

Method of introduction (tick ones which apply and give evidence)

- deliberate commercial introduction...
  or associated unintentional introduction..
- transport on ships' hulls ....
- transport in ballast water...
- rafting/floating ....
- carriage by birds..
- others (name)...

Reasons for success (indicate if speculative)

- lack of predators..
- rapid growth rate..
- opportunistic gap filler..
- favourable physical conditions...
- others (name)...

Rate of spread and methods involved

- spread rate in miles/time...
- marginal (up to 30 miles) indicate if by
  larval dispersal, mobile individuals etc..
- remote (over 30 miles) - if by methods
  of introduction (see above), indicate which..

Distribution

- point(s) where first introduced to Britain..
- extent of current distribution...
- centres of population around Britain...
- distribution in Europe (if non-European in origin)..

Effects on the environment

- physical displacement of native species...
- predation on native species...
- negligible (e.g. innocuous gap filler)..
- others (specify)...

Effects on commercial interests

- pest or parasite..
- fouling organism..
- other...

Control methods used and effectiveness

Please indicate whether used, how and effectiveness:

- chemical..
- biological...
- physical...

Factors likely to influence spread and distribution

- lethal temperatures...
- temperature required for reproduction..
- other conditions for reproduction...
- longevity..
- known predators...

Beneficial effects

- increased biodiversity..
- commercially important species...
- other...

Lessons to be learnt or other comments

References

Part 2: Directory of non-native marine species in British waters

Flora

Bacillariophyta

Thalassiosira punctigera

Division:	Bacillariophyta
Class:	Coscinodiscophyceae
Order:	Thalassiosirales
Species name:	*Thalassiosira punctigera* Castr.
Synonyms:	*Thalassiosira angstii* (Gran) MaKarova
Common name:	A centric diatom

Date of introduction and origin

Thalassiosira punctigera was first detected in English waters (Plymouth, Devon) in 1978 (Wallentinus in press; G.R. Hasle pers. comm.). Its origin is unknown although it had only previously been recorded from the North Pacific and South Atlantic Oceans, plus one record from the Carribean (Hasle 1983).

Method of introduction

The method of introduction is unknown, but ballast transport cannot be ruled out and imported oysters have also been hypothesised as a potential vector (Rincé & Paulmier 1986; Wallentinus in press).

Reasons for success

Unknown.

Rate of spread and methods involved

It was reported from English waters and Helgoland in 1978; Norway in 1979; Netherlands in 1981 (Marine Biological Association 1979; Hasle 1990; Smayda 1990). Its method of spread is unknown.

Distribution

It is found in the English Channel and North Sea (Wallentinus in press).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

It is an extremely variable species with regard to size and valve structure (Hasle 1983). It was very abundant in the English Channel in the period 1980-1981 but has subsequently been considered to have an insignificant role (Boalch 1987).

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Thalassiosira tealata

Division:	Bacillariophyta
Class:	Coscinodiscophyceae
Order:	Thalassiosirales
Species name:	*Thalassiosira tealata* Takano
Synonyms:	None
Common name:	A centric diatom

Date of introduction and origin

Thalassiosira tealata was first detected in English waters at Blakeney, Gloucestershire, in 1950 (Wallentinus in press). Its origin is unknown. As it was not found in Atlantic plankton samples prior to 1950 it is presumed to be an introduction. It has also been found in Japanese waters (Takano 1980).

Method of introduction

The method of introduction is unknown, but ballast transport cannot be ruled out and imported oysters have also been hypothesised as a potential vector (Rincé & Paulmier 1986; Wallentinus in press).

Reasons for success

Unknown.

Rate of spread and methods involved

It was found in English waters in 1950 and off Norway in 1968 (G.R. Hasle pers. comm. in Wallentinus in press). The method of spread is unknown.

Distribution

It is distributed from the English Channel to Norway (Wallentinus in press).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

The sample containing *Thalassiosira tealata* was collected near Blakeney, Gloucestershire from the river Severn in 1950, but not examined at that time. Its presence in European waters was known for some years (G.R. Hasle pers. comm.) but the species was not described until 1980 by Takano.

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Prof. G.R. Hasle, University of Oslo.

Coscinodiscus wailesii

Division:	Bacillariophyta
Class:	Coscinodiscophyceae
Order:	Coscinodiscales
Species name:	*Coscinodiscus wailesii* Gran & Angst
Synonyms:	None known
Common name:	A centric diatom

Date of introduction and origin

Coscinodiscus wailesii was first detected in the English Channel in 1977 (as *Coscinodiscus nobilis* Grunow) and is thought to originate from the Indian and Pacific Oceans (Boalch & Harbour 1977; Boalch 1987; Wallentinus in press).

Method of introduction

Unknown method of introduction, but ballast water transport cannot be ruled out and importation with oysters has been hypothesised as another potential vector (Rincé & Paulmier 1986; Wallentinus in press).

Reasons for success

Unknown.

Rate of spread and methods involved

It spread rapidly and was recorded from the English Channel (near Plymouth, Devon) in 1977; Atlantic coast of France by 1978 and Norway by 1979 (Hasle 1990; Wallentinus in press).

Distribution

It is found in the English Channel, Atlantic coast of France, Frisian Islands, Helgoland and Norway (Rincé & Paulmier 1986; Wallentinus in press).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

It can reach high numbers and produce copious mucilage which 'in sinking' can accumulate insoluble skeletons of planktonic organisms and mineral particles, increasing its volume and density (Boalch & Harbour 1977) and blanket the seabed.

Effects on commercial interests

Fishing trawls may become clogged or broken by heavy grey slime. It may interfere with the hauling of fishing gear and prolonged washing or air drying may not completely remove it (Boalch & Harbour 1977).

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Boalch (1987) reported *Coscinodiscus wailesii* to be still present in the Plymouth area and to have become a major constituent of the winter centric diatom population.

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Odontella sinensis

Division:	Bacillariophyta
Class:	Coscinodiscophyceae
Order:	Triceratiales
Species name:	*Odontella sinensis* Grun.
Synonyms:	*Biddulphia sinensis* Grev.
Common name:	A centric diatom

Date of introduction and origin

Odontella sinensis came to European waters in 1889; it was first noted in the North Sea in 1903 and in British waters in 1906 (see Ostenfeld (1908) for details of its spread). It was originally described from the China Sea (Greville 1866 in Boalch & Harbour 1977), but Ostenfeld (1908) considered it was most probably introduced from the Red Sea or Indian Ocean.

Method of introduction

Ballast transport was tentatively suggested by Ostenfeld (1908) and Wallentinus (in press) considers this method of introduction cannot be ruled out.

Reasons for success

Unknown.

Rate of spread and methods involved

It rapidly spread to become widely distributed throughout European waters in less than 10 years (Ostenfeld 1908; Boalch & Harbour 1977; Boalch 1987; Christensen, Koch & Thomsen 1985).

Distribution

Odontella sinensis has a wide Atlantic distribution including the Baltic Sea (Wallentinus in press) and is now considered to be an important constituent of the winter and spring diatom flora around Britain (Boalch 1987).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

This species has been a prominent contributor to the winter and spring phytoplankton of the western English Channel (Boalch & Harbour 1977; Boalch 1987).

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None known.

Beneficial effects

None.

Comments

None.

References

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Acknowledgements (contributors)

Prof. G.R. Hasle, University of Oslo.

Pleurosigma simonsenii

Division:	Bacillariophyta
Class:	Bacillariophyceae
Order:	Naviculales
Species name:	*Pleurosigma simonsenii* Hasle
Synonyms:	*Pleurosigma planctonicum* Simonsen (non *P. planctonicum* Cleve-Euler)
Common name:	A pennate diatom

Date of introduction and origin

Pleurosigma simonsenii was first detected in the English Channel during 1966 and is thought to originate from the Indian Ocean (Simonsen 1974; Boalch & Harbour 1977a; Wallentinus in press).

Method of introduction

The method of introduction is not known, but ballast transport cannot be ruled out (Wallentinus in press).

Reasons for success

Unknown.

Rate of spread and methods involved

It was found in the English Channel (off Ushant, on the French coast) in 1966; and off The Netherlands by 1974 (Wallentinus in press). The method of spread is unknown.

Distribution

It has been sporadically reported in the English Channel and southern North Sea, but it may have more or less disappeared since these reports were received (Wallentinus in press; Smayda 1990; International Council for the Exploration of the Sea 1983).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

Presumably *Pleurosigma simonsenii* has displaced native species at times since it was reported dominant in the Plymouth area in 1973; it has since 'settled down' to a minor constituent of the plankton (Boalch & Harbour 1977b; Boalch 1987; Wallentinus in press).

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Currently it is considered a minor constituent of the British phytoplankton (Boalch & Harbour 1977a).

References

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Acknowledgements (contributors)

Prof. G.R. Hasle, University of Oslo.

Rhodophyta

Asparagopsis armata

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Bonnemaisoniales
Species name:	*Asparagopsis armata* Harvey
Synonyms:	*Falkenbergia rufolanosa* (Harvey) Schmitz (part of life cycle)
Common name:	Harpoon weed

Date of introduction and origin

Asparagopsis armata was first recorded in 1949 on Lundy in the Bristol Channel. The *Falkenbergia* phase was recorded by Harvey & Drew (1949); the gametangial condition of *Asparagopsis armata* was first recorded from Cornwall by Drew (1950). It had been introduced from mainland Europe. It was first recorded in Ireland in 1939 (Valéra 1942). The species originates from Australia and/or possibly New Zealand.

Method of introduction

It was introduced to mainland Europe, possibly as an associated unintentional introduction with oysters (it was first recorded in Algeria in 1923) (Feldman & Feldman 1942), then probably introduced to Britain and Ireland by rafting and floating.

Reasons for success

The species has a lack of predators and a rapid growth rate. It is also an opportunist.

Rate of spread and methods involved

The species was present in Ireland in 1939, Lundy in 1949, Plymouth (Devon) in 1950, Start Point (south Devon) in 1953 and the Solent in 1973, and arrived in Shetland by 1973 (Irvine *et al.* 1975).

Distribution

It is distributed throughout the British Isles although uncommon on the east coast (Irvine *et al.* 1975). European populations can be found from the western Mediterranean to Shetland and it is especially common on the coast of Spain (South & Tittley 1986).

Factors likely to influence spread and distribution

Lethal temperatures and temperature required for reproduction are likely to restrict distribution. The hooked branches are likely to spread by attachment onto floating objects (Farnham 1980).

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

There are two macroscopic phases to the life cycle of *Asparagopsis armata*, the filamentous habit being very similar in appearance to that of *Bonnemaisonia hamifera* but readily distinguished at the cellular level (D.A. Birkett pers. comm.).

References

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Acknowledgements (contributions from questionnaire)

Mr I. Tittley, Natural History Museum, London.

Bonnemaisonia hamifera

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Bonnemaisoniales
Species name:	*Bonnemaisonia hamifera* Hariot
Synonyms:	*Trailliella intricata* Batt. (part of life cycle)
Common name:	None

Date of introduction and origin

Bonnemaisonia hamifera was first found in Falmouth, Cornwall, and Studland, Dorset, in 1893 (Holmes 1897) although the tetrasporangial phase *Trailliella* was first collected from Dorset in 1890 (Farnham 1980). This species originates in the Pacific and was probably introduced from Japan.

Method of introduction

The exact method is unknown but it is considered to have been introduced unintentionally with shellfish (I. Tittley pers. comm.).

Reasons for success

Lack of grazers, rapid growth rate, and its opportunistic qualities have contributed to its success.

Rate of spread and methods involved

This species has spread from Cornwall in 1893 to the Orkney Islands by 1929, and Shetland by 1949 by both marginal (up to 30 miles) and remote (beyond 30 miles) dispersal. It was found in Norway in 1916 and the Faroes in 1980.

Distribution

This species is distributed throughout the British Isles, although is uncommon on the east coast. In Europe it is found from Norway to the Azores including Ireland (Irvine 1982; South & Tittley 1986; Westbrook 1930).

Factors likely to influence spread and distribution

It is restricted in Britain by cold temperatures and the temperature required for reproduction.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

There are two macroscopic phases to the life of this species, the filamentous *Trailliella* "pink cotton wool" phase being very difficult to distinguish from the same life phase of related species (D.A. Birkett pers. comm.).

References

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Acknowledgements (contributions from questionnaire)

Mr I. Tittley, Natural History Museum, London.

Grateloupia doryphora

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Cryptonemiales
Species name:	*Grateloupia doryphora* (Montagne) Howe
Synonyms:	*Halymenia doryphora* Montague, *Halymenia lanceola* J. Agardh, *Grateloupia lanceola* (J. Agardh) J. Agardh etc. (see Farnham 1978).
Common name:	None

Date of introduction and origin

Grateloupia doryphora was first collected in 1969 from Southsea, Hampshire (Farnham & Irvine 1973). It may have originated in the Atlantic or Pacific (W.F. Farnham pers. comm.).

Method of introduction

Probably associated with oyster mariculture, at least in France (W.F. Farnham pers. comm.).

Reasons for success

Lack of grazers (C.A. Maggs pers. comm.), sheltered growth conditions, high level of nutrients in water, tolerance to lowered salinities and elevated seawater temperatures in the summer (Farnham 1980) account for its success.

Rate of spread and methods involved

It has spread slowly, probably through marginal dispersal (up to 30 miles) by natural means (W.F. Farnham and I. Tittley, pers. comms.), perhaps by movement of plants attached to small stones.

Distribution

In England it occurs off Bognor Regis and elsewhere in the sublittoral, West Sussex, and along the Hampshire coast to Lepe in the Solent (Farnham 1980). It is now found around the Isle of Wight, in the Fleet Lagoon, Dorset, and Jersey (W.F. Farnham pers. comm.). The only known mainland European populations are in Portugal (South & Tittley 1986) and, more recently, it has been discovered in Brittany.

Factors likely to influence spread and distribution

Water turbidity and competition from indigenous sublittoral algae and probably discourage extensive development in the sublittoral (Farnham 1980).

Effects on the environment

Unknown.

Effects on commercial interests

This species is used in the Pacific as a food and as an industrial source of carrageenan.

Control methods used and effectiveness

None.

Beneficial effects

None known.

Comments

Where the two co-exist, *G. doryphora* usually out competes the other non-native, *G. filicina* var. *luxurians* (W.F. Farnham pers. comm.). The ribbon-like blades of this seaweed can reach a size of 100 cm by 20 cm, but are usually much smaller (Irvine & Farnham 1983).

References

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Acknowledgements (contributions from questionnaire)

Mr I. Tittley, Natural History Museum, London.

Dr W.F. Farnham, University of Portsmouth.

Grateloupia filicina *var.* luxurians

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Cryptonemiales
Species name:	*Grateloupia filicina* (Lamouroux) C. Agardh var. *luxurians* A. & E.S. Gepp
Synonyms:	Various synonyms exist for this species and variety, see Farnham (1978)
Common name:	None

Date of introduction and origin

Grateloupia filicina var. *luxurians* was first introduced into the Solent before 1947 (Farnham & Irvine 1968; Farnham 1978, 1980). It occurs in the Pacific, Indian, and warmer parts of the Atlantic Oceans (Farnham 1980) and was possibly introduced from around Japan.

Method of introduction

It probably arrived in France at least with oysters as an unintentional associated introduction (C.A. Maggs pers. comm.).

Reasons for success

This species has high reproductive rate and is fertile for much of the year.

Rate of spread and methods involved

Despite the species' high reproductive rate it has spread very slowly.

Distribution

There are populations of this species in Dorset, Hampshire, Isle of Wight and Sussex (see Farnham (1980) for map). Recently, further populations have been found in Jersey (W.F. Farnham pers. comm.). European populations are present in the Mediterranean and in Brittany.

Factors likely to influence spread and distribution

It is possible that low temperatures in certain parts of Great Britain may affect this species.

Effects on the environment

Unknown, but see under comments.

Effects on commercial interests

It grows in marinas but is unlikely to be a nuisance.

Control methods used and effectiveness

None used.

Beneficial effects

This species is used in the western Pacific as a food and as a source of carrageenan.

Comments

The fronds of this seaweed can reach a length of 70 cm (Irvine & Farnham 1983), compared with up to 10 cm for the native variety *G. filicina* var. *filicina*. The non-native may be capable of displacing other species, on account of its potential size (R. Mitchell pers. comm.) although there is no inidication of this happening (W.F. Farnham pers. comm.).

References

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Acknowledgements (contributions from questionnaire)

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Pikea californica

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Gigartinales
Species name:	*Pikea californica* Harvey
Synonyms:	None
Common name:	Captain Pike's weed

Date of introduction and origin

Pikea californica was first recorded from the Isles of Scilly off south-west England in 1983 (Hiscock 1984), although examination of herbarium specimens showed that the population was present in 1967 (Maggs & Guiry 1987). This species is known from the west coast of North America. It is thought to have been introduced from California (Maggs & Guiry 1987), possibly having arrived during World War II.

Method of introduction

Flying boats flew directly from California to the Isles of Scilly during World War II and Crisp (1958) reported that seaplane hulls and floats are occasionally fouled by algae. This species may have been transferred by *Catalinas* employing canvas sea anchors (stored in the hull while flying which would consequently have been damp but aerated), since it appears to be physiologically robust and, furthermore, the planes flew at relatively low altitudes (Maggs & Guiry 1987). However, Maggs & Ward (1996) have carried out a recent survey of the Californian coast and report that *Pikea californica* does not currently occur around San Diego, where the seaplanes were manufactured. They have no other suggestions concerning the vector used for transporting this species from California.

Reasons for success

The limited temperature range in the Isles of Scilly may favour this species (see Maggs & Guiry 1987).

Rate of spread and methods involved

Pikea californica has not been found elsewhere in Great Britain and may be confined to favourable conditions found in the Isles of Scilly.

Distribution

This species is restricted in Britain to the Isles of Scilly (Maggs & Ward 1996) and has not been recorded anywhere else in Europe.

Factors likely to influence spread and distribution

This species is possibly limited by winter temperatures in Britain (Maggs & Guiry 1987).

Effects on the environment

Possible displacement of native species, but likely to be insignificant.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

In order to recognise this species, examination of the distinctive anatomical detail is required (D.A. Birkett pers. comm.). Recent research has shown that Japanese populations of '*Pikea californica*' are in fact another species (Maggs & Ward 1996).

References

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Acknowledgements (contributions from questionnaire)

Dr C.A. Maggs, Queen's University of Belfast.

Agardhiella subulata

Division: Rhodophyta

Class:	Rhodophyceae
Order:	Gigartinales
Species name:	*Agardhiella subulata* (C. Agardh) Kraft & Wynne
Synonyms:	*Neoagardhiella baileyi* (Kutzing) Wynne & Taylor
Common name:	None

Date of introduction and origin

Agardhiella subulata was first introduced into the Solent before 1973 (Farnham & Irvine 1979). It is thought to have originated in the Pacific or the east coast of the USA (C.A. Maggs pers. comm.).

Method of introduction

It was perhaps introduced unintentionally with shellfish (W.F. Farnham pers. comm.).

Reasons for success

Unknown.

Rate of spread and methods involved

Unknown.

Distribution

This species is restricted in Britain to the Solent. It is still sporadic in occurrence, but is mainly localised to Langstone and Chichester harbours, West Sussex. It may also occur in Spain, but this record needs to be confirmed (W.F. Farnham pers. comm. 1995). Other than these, no European populations are known, but are anticipated.

Factors likely to influence spread and distribution

Unknown. (This species has been introduced into the Solent but appears unable to spread except on a slow, gradual basis.)

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

It may be a potential source of carrageenan (W.F. Farnham pers. comm.).

Comments

Taxonomic research remains to be done to establish which species this is and thereby indicate where it has come from (e.g. see Farnham 1980). The species present in the Solent may be *Neoagardhiella gaudichaudii*, not *A. subulata* but W.F. Farnham (pers. comm.) recommends acceptance as *A. subulata* for now.

References

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Acknowledgements (contributions from questionnaire)

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Solieria chordalis

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Gigartinales
Species name:	*Solieria chordalis* (Agardh) J. Agardh
Synonyms:	None
Common name:	None

Date of introduction and origin

Solieria chordalis was introduced around 1976 from northern France into Falmouth Harbour (Cornwall), and the Fleet and Weymouth Bay (Dorest) (Farnham & Jephson 1977).

Method of introduction

It was possibly transported on ships' hulls (Farnham 1980), although perhaps also on ballast stones in recent historical times. Weed-rafting of stones may also have been a natural mechanism for dispersal across the Channel (W.F. Farnham pers. comm.).

Reasons for success

It spreads using vegetative regeneration from basal, rhizoidal systems. (indeed no fertile gametophytes have been found), so despite lack of sexual reproduction, the asexual methods are very effective.

Rate of spread and methods involved

It has spread slowly. A disjunct distribution is suggestive of remote dispersal methods such as shipping (Farnham 1980).

Distribution

Currently it is found in western Wales, Dorset and Cornwall (Hiscock & Maggs 1984). Elsewhere in Europe it is found in France (Farnham 1980), Spain and in the western Mediterranean (South & Tittley 1986; I. Tittley, pers. comm.).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

None known.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

It could be cultivated to produce carrageenan.

Comments

Previously it was considered that, as well as *Solieria chordalis* on the south coast, *Solieria filiformis* was present in Milford Haven, South Wales. However, W.F. Farnham (pers. comm.) indicates that the Milford Haven population (Farnham 1980; Farnham & Irvine 1979) was misidentified and is probably better referred to as *S. chordalis* (the only known species of this genus in Britain).

References

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South, G.R., & Tittley, I. 1986. *A checklist and distributional index of the benthic marine algae of the North Atlantic Ocean.* St. Andrews & London, Huntsman Marine Laboratory & British Museum (Natural History).

Acknowledgements (contributions from questionnaire)

Dr C.A. Maggs, Queen's University of Belfast.

Dr W.F. Farnham, University of Portsmouth.

Mr I. Tittley, Natural History Museum, London.

Antithamnionella spirographidis

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Ceramiales
Species name:	*Antithamnionella spirographidis* (Schiffner) Wollaston
Synonyms:	*Antithamnion spirographidis* Schiffner, *Antithamnion tenuissimum* Gardner

Common name: None

Date of introduction and origin

Antithamnionella spirographidis was first reported from Plymouth docks by Westbrook (1934). It was introduced to Europe prior to 1911 (C.A. Maggs pers. comm.) and was introduced to Britain from the Mediterranean. It is thought to have originated in the North Pacific (Lindstrom & Gabrielson 1989).

Method of introduction

It was probably carried on the hulls and mooring ropes of ships, although it could also have been introduced with oysters.

Reasons for success

A very rapid vegetative reproduction accounts for its success.

Rate of spread and methods involved

It spreads by remote dispersal through shipping activities, aided by its ability to grow on ropes, buoys and other artificial surfaces such as plastic (C.A. Maggs pers. comm.).

Distribution

The species is found on the south coast of England, south and west coasts of Wales, Ireland, and the west coast of Scotland. European populations occur in northern France and in the Mediterranean.

Factors likely to influence spread and distribution

Although ephemeral, this species spreads by fragmentation and the rapid production of new thalli.

Effects on the environment

Unknown.

Effects on commercial interests

It may cause fouling in marinas.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Wollaston (1986) commented that *Antithamnionella spirographidis* was introduced into Australia from Europe by shipping and it is associated with dockyards and harbours. In their natural habitats, *Antithamnionella spirographidis* and *A. ternifolia* are very similar in appearance so microscopic examination is required to distinguish them (Maggs & Hommersand 1993).

References

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Acknowledgements (contributions from questionnaire)

Dr C.A. Maggs, Queen's University of Belfast.

Antithamnionella ternifolia

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Ceramiales
Species name:	*Antithamnionella ternifolia* (J.D. Hooker & Harvey) Lyle
Synonyms:	*Antithamnionella sarniensis* Lyle, *Antithamnion sarniensis* (Lyle) Feldmann-Mazoyer
Common name:	None

Date of introduction and origin

Antithamnionella ternifolia was first recorded in 1906 from Plymouth, Devon (Maggs & Hommersand 1993). This species was introduced from the southern hemisphere (possibly Australia), where it is native.

Method of introduction

It was probably carried on the hulls and mooring ropes of ships.

Reasons for success

The species has a rapid growth rate and grows abundantly on all types of substrata including eelgrass leaves, algae, animals, pebbles and artificial materials, over a wide range of conditions (Maggs & Hommersand 1993).

Rate of spread and methods involved

It has spread fairly rapidly around the coast of Britain, from Plymouth to western Ireland in 30 years (C.A. Maggs pers. comm.). It spreads mainly through remote (over 30 miles, through the influence of man) dispersal as it grows on ropes and ships' hulls.

Distribution

It is widely distributed on the south and west coasts of Britain as far north as Strathclyde (formerly Argyll) in Scotland (Maggs & Hommersand 1993). There are European populations from the Netherlands south as far as Portugal.

Factors likely to influence spread and distribution

This species shows a wide temperature tolerance. Sexual reproduction is rare; the species spreads by fragmentation.

Effects on the environment

No effects are known.

Effects on commercial interests

It is a fouling organism.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

More taxonomic research is required to determine whether other southern hemisphere species are conspecific. In their natural habitats, *Antithamnionella spirographidis* and *A.ternifolia* are very similar in appearance so microscopic examination is required to distinguish them.

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Acknowledgements (contributions from questionnaire)

Dr C.A. Maggs, Queen's University of Belfast.

Polysiphonia harveyi

Division:	Rhodophyta
Class:	Rhodophyceae
Order:	Ceramiales
Species name:	*Polysiphonia harveyi* Bailey
Synonyms:	*Polysiphonia insidiosa* P. & H. Crouan
Common name:	None

Date of introduction and origin

Polysiphonia harveyi was introduced before 1908 onto the south coast of England, possibly from northern France where it was found in 1832 (Maggs & Hommersand 1993). This species may have originated in the Pacific Ocean and was possibly introduced from Japan.

Method of introduction

It was an associated unintentional introduction with oysters.

Reasons for success

It has a rapid growth rate and is an opportunist.

Rate of spread and methods involved

Its rate of spread is not known. There is a small chance it may have spread through drifting with larger weeds on which it is an epiphyte (Wallentinus in press).

Distribution

It is found on the south and east coasts of England to Essex and up the western coast to Scotland. European populations occur from Norway to the Mediterranean, including Ireland (Maggs & Hommersand 1993).

Factors likely to influence spread and distribution

It is very tolerant of temperature changes.

Effects on the environment

It possibly displaces native species as it can become very abundant.

Effects on commercial interests

It is a fouling agent as it is abundant in marinas on artificial structures, but as it is small, this is not a significant problem.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Japanese populations are interfertile with British populations of *Polysiphonia harveyi* (C.A. Maggs pers. comm.), but the correct taxonomy is still to be determined, possibly involving *Polysiphonia strictissima* (described from New Zealand). All species of *Polysiphonia* require microscopic examination to confirm their identification.

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Acknowledgements (contributions from questionnaire)

Dr C.A. Maggs, Queen's University of Belfast.

Chromophyta

Colpomenia peregrina

Division:	Chromophyta
Class:	Phaeophyceae
Order:	Dictyosiphonales
Species name:	*Colpomenia peregrina* (Sauvageau) Hamel
Synonyms:	*Colpomenia sinuosa* (Mertens ex Roth) Derbès et Solier var. *peregrina* Sauvageau
Common name:	Oyster thief

Date of introduction and origin

Colpomenia peregrina was introduced in 1907 from France into Cornwall and Dorset (Cotton 1908). This species occurs naturally in the Pacific Ocean and was introduced from the Pacific coast of North America.

Method of introduction

It was introduced to France from the Pacific coast of America with juvenile American oysters *Crassostrea virginica*. There was natural migration from France to Britain, and it may also have been introduced unintentionally with commercial oysters from France.

Reasons for success

This species lacks predators and has a rapid growth rate.

Rate of spread and methods involved

It has spread throughout Britain from southern England in 1907 to the Isle of Man by 1923, the Outer Hebrides by 1936 and the Orkneys by 1940 (Lund 1949; Norton 1976; Wilkinson 1975), marginally by natural means of dispersion.

Distribution

It is distributed throughout Britain although populations are larger on western coasts. In Europe it is found from Iberia to southern Norway. It has a world-wide distribution in temperate waters (South & Tittley 1986).

Factors likely to influence spread and distribution

Temperature and other conditions for reproduction affect its spread.

Effects on the environment

It has negligible effects on the environment.

Effects on commercial interests

When growing attached to oysters it floats away with the oyster when the air-filled thalli grow large enough, hence its name of oyster thief (Farnham 1980) but this does not occur in England.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

It is found almost world-wide in temperate areas. There is some debate as to whether *Colpomenia peregrina* and *C. sinuosa* are separate species or variants of a single species.

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Acknowledgements (contributions from questionnaire)

Mr I. Tittley, Natural History Museum, London.

Undaria pinnatifida

Division:	Chromophyta
Class:	Phaeophyceae
Order:	Laminariales
Species name:	*Undaria pinnatifida* (Harvey) Suringer
Synonyms:	None
Common names:	Wakame (in Japan), Japanese kelp

Date of introduction and origin

Undaria pinnatifida was found attached to floating pontoons in the Hamble estuary in the Solent, Hampshire on 15 June 1994 (Fletcher & Manfredi 1995). It is native to the west coast of Japan. Its introduction to Europe was initially to France where it was found in 1971 in Etang de Thau, a saltwater lagoon on the Mediterranean coast (Perez, Lee & Juge 1981; Boudouresque, Gerbal & Knoepffler-Peguy 1985).

Method of introduction

The most likely vector for the initial introduction of *Undaria pinnatifida* to Europe was imported spat of Pacific oysters *Crassostrea gigas* (Perez, Lee & Juge 1981; Boudouresque, Gerbal & Knoepffler-Peguy 1985). However, because of its commercial importance, subsequent introductions in France were intentional, and attempts were made in 1981 to cultivate plants on rope in the Mediterranean (Perez, Lee & Juge 1981) and later, since 1983, successful attempts at cultivation have been made on the Atlantic coast at several sites in Brittany (Perez, Kaas & Barbaroux 1984; Perez *et al.* 1988; Boudouresque, Gerbal & Knoepffler-Peguy 1985; Castric-Fey, Girard & L'Hardy-Halos 1993; Wallentinus in press). This alga was also reported from Spain in 1990, having been introduced with imported oysters (Wallentinus in press).

Its introduction from France to Britain is thought to have been on ships' hulls (Fletcher & Manfredi 1995). Such spread via boats using ports in the English Channel was predicted by Hay (1990).

Reasons for success

It produces millions of spores with motile periods of up to 5 hours and has a propensity for colonising floating objects (Fletcher & Manfredi 1995) which suggests it can easily be spread locally by natural dispersion and more remotely through the agency of shipping.

Five reasons likely to give competitive edge over native species were listed by Fletcher & Manfredi (1995) from observations on introduced populations in Brittany and the Pacific:

- its behaviour as an opportunistic weed and its ability to rapidly colonise new or disturbed substrata and artificial floating structures;
- its occurrence in dense, vigorous stands on benthic shores, forming a thick canopy over the subordinate biota;
- its occupancy of a wide range of shores varying in exposure;
- its extensive vertical distribution, from low tide level down to 15 m in suitably clear waters;
- the extended period of reproductive spore formation and release observed in introduced populations.

Rate of spread and methods involved

Short distance, marginal spread occurs by natural reproductive processes; while spread along the coast and probably across the Channel is likely to be associated with shipping and coastal boat traffic (Hay 1990; Fletcher & Manfredi 1995; Wallentinus in press).

Distribution

In British waters it was first found in the Hamble estuary in the Solent but has more recently been found at scattered locations on the Isle of Wight, in Torquay in Devon, in a marina on Jersey in the Channel Isles (R.L. Fletcher pers. comm.). Elsewhere in Europe it occurs on the French Mediterranean coast, on the north and south coasts of Brittany, and on the Atlantic coast of Spain around Ria de Arosa (Wallentinus in press).

Factors likely to influence spread and distribution

Fletcher & Manfredi (1995) predicted that coastal boating traffic would be the means of significant spread of this species in northern European waters.

Effects on the environment

It may cause displacement of other native species (Fletcher & Manfredi 1995).

Effects on commercial interests

Undaria is a commercially important edible species. It is a fouling agent.

Control methods used and effectiveness

It is planned to remove all subsequently occurring plants from the marina pontoons in the Hamble. However, this is thought unlikely to eradicate the species or halt its local spread (Fletcher & Manfredi 1995).

Beneficial effects

Undaria is a commercially important species, cultivated for food (Guiry & Blunden 1991).

Comments

The intentional introduction of *Undaria* to the north coast of France and its continued farming has been considered extensively and sanctioned by the International Council for the Exploration of the Sea. Proposals to introduce this species to Ireland were rejected (Wallentinus in press).

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Acknowledgements (contributions from questionnaire)

Dr R.L. Fletcher, University of Portsmouth.

Sargassum muticum

Division:	Chromophyta
Class:	Phaeophyceae
Order:	Fucales
Species name:	*Sargassum muticum* (Yendo) Fensholt
Synonyms:	See Critchley *et al.* (1990) for discussion of taxonomic identity
Common name:	Jap weed, wire weed, strangle weed

Date of introduction and origin

Sargassum muticum was first found attached in Bembridge, Isle of Wight, in 1971 where it had arrived from France (Farnham, Fletcher & Irvine 1973). Critchley, Farnham & Morrell (1983) indicated that it was probably first found in the English Channel in the late 1960s and Farnham (1980) indicated by at least 1966. This species naturally occurs in Japanese and Chinese waters.

Method of introduction

It was an associated unintentional introduction with commercial introductions of oysters from the Canadian state of British Columbia or Japan to France. Spread from northern France is presumed to have occurred by natural means. Spores may be transported in ballast water, on ships' hulls and by rafting or floating of entire plants or detached fragments (Critchley *et al.* 1990). Marginal dispersal (up to 30 miles) is most likely to occur by the latter method (Farnham *et al.* 1981).

Reasons for success

This species has a rapid growth rate (Hales & Fletcher 1989). It is highly fecund (Norton & Deysher 1989), producing fertile receptacles which are cast off during the summer months. These float and can survive for up to 3 months (Farnham *et al.* 1981). The receptacles are androgynous with self-fertilisation; viable germlings are released.

Rate of spread and methods involved

It spread rapidly along the English south coast at about 30 km/year and along the north-west American coast at an average rate of about 60 km/year, mostly by drifting, fertile adults (Farnham *et al.* 1981).

Distribution

It is found in the Isles of Scilly, entire Channel coast (Hiscock & Moore 1986; Devon Wildlife Trust 1993) and east coast north to Suffolk, however the Norfolk population appears to be no longer extant (Critchley, Farnham & Morrell 1983; W.F. Farnham pers. comm.). It was recorded from south Wales as drift specimens in 1983 (N.C. Eno pers. obs.) and Lundy in 1993 (Andrew Gibson pers. comm.), and as attached specimens from Strangford Lough, Northern Ireland, in 1995 (Boaden 1995) and Constantine Bay, north Cornwall, in 1991 (K. Hiscock pers. comm.). Plants 2-3 years old were found in Crackington Cove, north Cornwall, in 1992 (W.F. Farnham pers. comm.). Elsewhere in Europe it is known from the Mediterranean and along the North Sea and Atlantic coasts of Portugal, Spain, France, Belgium, The Netherlands, Denmark, southern Norway and Sweden (Critchley, Farnham & Morrell 1983; Rueness 1989; W.F. Farnham pers. comm.).

Factors likely to influence spread and distribution

Higher temperatures are favourable and will encourage its spread further south. Lower temperatures are unfavourable and will limit its spread north. Ideal conditions for growth are

25°C and 34‰ salinity, although this species will grow at temperatures from 10 to 30° and salinities from 6.8 to 34‰.

Effects on the environment

It causes the physical displacement of native species through over-growing and shading underlying species (Critchley, Farnham & Morrell 1986). There is documented replacement of *Laminaria saccharina* and *Zostera marina* at Grandcamp on the French Atlantic coast (Givernaud, Cosson & Givernaud-Mouradi 1991). In Britain, there is observed growth of *Sargassum* on eel-grass beds in the Isles of Scilly (Raines *et al.* 1992) and in deep pools and channels *Halidrys siliquosa* can be displaced by *Sargassum muticum* as the dominant species (George, Tittley & Wood in prep.). Withers *et al.* (1975) reported a rich epiphytic community associated with *Sargassum* collected from the east Solent, suggesting that native epiphytic species are not particularly affected.

Effects on commercial interests

This species is a pest and fouling organism which is reported to interfere with recreational use of waterways, particularly when it becomes detached from hold fasts and floats off forming large masses (Farnham 1980). It blocks propellers and intakes (Critchley, Farnham & Morrell 1986). It is also a fouling organism on oyster beds and a nuisance to commercial fishermen, fouling their nets (Critchley, Farnham & Morrell 1981).

Control methods used and effectiveness

Removing *Sargassum* by hand is extremely time-consuming and needs to be repeated, probably indefinitely (Farnham 1980). Removal by trawling, cutting and suction have also been tried. Chemical methods using herbicide have been tried but failed due to lack of selectivity and the large doses needed. Small germlings can be consumed by molluscs and amphipods but this has no restrictive effect on *S. muticum.* Whatever method is used the alga always quickly regrows and effective methods for its permanent removal have not been found, although cutting and suction is the preferred method applied (Farnham *et al.* 1981; Critchley, Farnham & Morell 1986).

Beneficial effects

It is of possible commercial value to the alginate industry.

Comments

In its native habitat off the coast of Japan *S. muticum* is much smaller than in Britain (Rueness 1989). The eradication of this species in British waters has been attempted but has failed.

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Acknowledgements (contributions from questionnaire)

Prof. T. A. Norton, Port Erin Marine Laboratory.

Chlorophyta

Codium fragile *subsp.* atlanticum

Division:	Chlorophyta
Class:	Chlorophyceae
Order:	Codiales
Species name:	*Codium fragile* (Suringar) Hariot subsp. *atlanticum* (A. Cotton) Silva
Synonyms:	None
Common name:	Green sea fingers

Date of introduction and origin

Codium fragile subsp. *atlanticum* arrived in southwest Ireland in about 1808, from where it may have spread through rafting or floating (Silva 1955). It was found on the west coast of Scotland before 1840. This species is considered to have originated in the Pacific Ocean around Japan, and Silva (1955) considered it was introduced from there.

Method of introduction

It was unintentionally introduced to Ireland with shellfish.

Reasons for success

Lack of grazers has probably contributed to its success. It is an opportunist, exhibiting vegetative propagation and perennation.

Rate of spread and methods involved

It spread the length of Britain, including Shetland, since 1840 by marginal, natural dispersion. It spread from Berwick-upon-Tweed to St. Andrews, Fife, between 1949 and 1955, a distance of 80 km.

Distribution

Populations occur mainly in the north of Britain (C.A. Maggs pers. comm.). It is found from Dorset up the western coast of Britain, in Shetland (Irvine *et al.* 1975) and in east Scotland and Northumberland (Norton 1985; South & Tittley 1986). Elsewhere in Europe it is recorded only from Norway.

Factors likely to influence spread and distribution

Spread of this species is limited by cool summer temperatures, particularly on the east coast (Hardy 1981). This species is being displaced by *C. fragile* subsp. *tomentosoides* in Berwickshire (Hardy 1990).

Effects on the environment

It displaces the native species *Codium tomentosum* (Farnham 1980).

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

It is eaten in the Far East.

Comments

The subspecies of *C. fragile* found in Britain are only distinguishable microscopically. This has resulted in uncertainty as to when they were introduced and how they have spread. A third subspecies, *scandinavicum*, was introduced to Denmark in 1919 and Norway from Asiatic coasts of the Pacific.

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Acknowledgements (contributions from questionnaire)

Dr F.G. Hardy, University of Newcastle Upon Tyne.

Mr I. Tittley, Natural History Museum, London.

Codium fragile *subsp.* tomentosoides

Division:	Chlorophyta
Class:	Chlorophyceae
Order:	Codiales
Species name:	*Codium fragile* (Suringar) Hariot subsp. *tomentosoides* (van Goor) Silva
Synonyms:	None
Common name:	Green sea fingers

Date of introduction and origin

Codium fragile subsp. *tomentosoides* was introduced from mainland Europe to the River Yealm, Devon, in 1939 where it was first found at Steer Point (Silva 1955). This species originated in the Pacific Ocean around Japan.

Method of introduction

It spread remotely either as an associated unintentional introduction attached to shellfish such as oysters, attached to ships' hulls or as spores in ballast tanks; and marginally through rafting and floating.

Reasons for success

Lack of grazers has probably contributed to its success. It is an opportunist, exhibiting vegetative propagation and perennation.

Rate of spread and methods involved

This species was first collected in Holland in 1900 (van Goor 1923 quoted by Silva 1955) and has spread from Devon to Scotland since 1939 through marginal, natural dispersion by rafting and floating (I. Tittley pers. comm.). In Europe the initial spread was slow from the Netherlands but speeded up in the 1940s, possibly due to wartime shipping. Burrows (1991) considered it has spread fairly rapidly from the south coast northwards since its initial discovery.

Distribution

It is distributed throughout Britain, but particularly along the south coast of England and the west coast of Scotland (Hardy 1981; Hardy 1990; Irvine *et al.* 1975; South & Tittley 1986). Elsewhere in Europe it occurs on the south and west coasts of Ireland, the western Mediterranean and from Atlantic Spain (I. Fuller pers. comm.) to Norway.

Factors likely to influence spread and distribution

Temperature is likely to be a limiting factor to this species.

Effects on the environment

It displaces native species *Codium tomentosum* (Farnham 1980) although there is some recent indication that the native *Codium tomentosum* is making a comeback against this non-native (W.F. Farnham pers. comm.).

Effects on commercial interests

It is used as a food in the Far East.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

See comments on *C. fragile* subsp. *atlanticum*.

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Acknowledgements (contributions from questionnaire)

Dr F.G. Hardy, University of Newcastle-upon-Tyne.

Mr I. Tittley, Natural History Museum, London.

Dr C.A. Maggs, Queen's University of Belfast.

Anthophyta

Spartina anglica

Phylum:	Anthophyta
Class:	Magnoliopsida
Order:	Poales
Species name:	*Spartina anglica* C.E. Hubbard (fertile amphidiploid hybrid of *Spartina maritima* (Curt.) Fernald and *Spartina alterniflora* Lois.)
Synonyms:	Sterile diploid hybrid: *Spartina townsendii* (H. & J. Groves)
Common name:	Common cord-grass, Townsend's grass or ricegrass.

Date of introduction and origin

The smooth cord-grass *Spartina alterniflora* was introduced from the east coast of North America to Southampton Water prior to 1870 and was first found on mudflats near Hythe (Stapf 1913). Its subsequent crossing with the native small cord-grass *S. maritima* resulted in the appearance of a fertile amphidiploid, the common cord-grass *S. anglica* (and in the sterile hybrid *S. townsendii* which preceded it). Their identification is covered by Marchant (1967).

Method of introduction

It is thought that *Spartina alterniflora* was originally introduced in ships' ballast water.

Reasons for success

Following its formation through hybridisation and tetraploidy, *Spartina anglica* was successful through having a rapid rate of growth, high fecundity and aggressive colonisation (Benham 1990).

Rate of spread and methods involved

Following the appearance of *Spartina anglica*, it was extensively planted throughout Britain to stablise soft sediments (Hubbard & Stebbings 1967) and in Europe, China and eastern USA. *Spartina* has also spread naturally. At many sites it remained dormant as seeds for a number of years then showed a considerable expansion over a relatively short period. This expansion appears to be correlated with a year in which early seed development takes place and seedling establishment is extensive. Thereafter, clumps of *Spartina* arise by vegetative growth from seedlings and these gradually coalesce to form monospecific swards (Doody 1984).

Distribution

In Britain *Spartina anglica* is widespread around the east and west coasts and is still expanding in the west. However, on the south coast, having initially spread extensively, it died back (Doody, 1984). It is generally found in sheltered, estuarine conditions where mud flats are present. Elsewhere in Europe it is found in estuaries in the west (P. Doody pers. comm.).

Factors likely to influence spread and distribution

The availability of mud flats for colonisation, change in sediment patterns, tidal regimes and climate (it appears less able to set viable seed in colder climates) have influenced its spread.

Effects on the environment

The rapid colonisation of *Spartina* over extensive flats in sites with large wintering populations of waders and wildfowl is a major concern because of the birds' loss of habitat for feeding and roosting (Davidson *et al.* 1991). It is believed that *Spartina anglica* may have helped the die back of the native *S. maritima* as the latter is much less widely spread than formerly (Perring & Walters 1976). In addition, by taking over the mantle of the native pioneer species, *S. anglica* has altered the course of succession. It usually produces a monoculture which has much less intrinsic value to wildlife than the naturally species-diverse marsh (Davidson *et al.* 1991).

Effects on commercial interests

Amenity interests may be affected, though it has been used in the past as an aid to saltmarsh enclosure.

Control methods used and effectiveness

Before World War II, copper sulphate was sprayed on *Spartina* as a treatment (Hardy 1968). More recently there have been several attempts to control *Spartina anglica* where it has invaded nature reserves (Doody 1984) by spraying it with the herbicides Dalapon and Feneron, and attempts have also been made to dig up seedlings. Dalapon is reported to have been up to 80% successful, but is generally considered to be not very effective. Pesticide trials have been carried out at Lindisfarne National Nature Reserve off the Northumberland coast and at several other sites.

Beneficial effects

The ability of *Spartina* to colonise open mudflats at a faster rate, and further seaward, than its competitors has been seen as of potential benefit to man. As a consequence it was extensively planted throughout Britain (Hubbard & Stebbings 1967), in Europe, and even as far as China, as an aid to stabilisation of coastlines and a stimulus to enclosure and land-claim (Davidson *et al.* 1991).

Comments

Spartina anglica is now the main species of cord-grass found throughout Great Britain.

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Acknowledgements (contributions from questionnaire)

Dr J.P. Doody, Joint Nature Conservation Committee.

Fauna

Cnidaria

Gonionemus vertens

Phylum:	Cnidaria
Class:	Hydrozoa
Order:	Limnomedusae
Species name:	*Gonionemus vertens* A. Agassiz 1862
Synonyms:	None
Common name:	None

Date of introduction and origin

Gonionemus vertens was first reported from north-east England in 1913 and probably originates from the western Pacific (China, Korea or Japan) via Portugal (Edwards 1976).

Method of introduction

Transport on ships' hulls in the polyp stage (Carlton 1985) from the western Pacific Ocean in the 19th century may be the mechanism of introduction. Edwards (1976) suggested that it may have arrived much earlier from Japan with importations of Japanese oysters *Crassostrea gigas* 500 or more years ago; he also discusses other shipping- and seaplane-associated methods of transport.

Reasons for success

This species seems to thrive in temperate to warm-temperate regions.

Rate of spread and methods involved

This species shows a variable, generally moderate rate of spread. It is thought to have been initially introduced to Europe in Portugal where the population was localised due to currents, temperatures and salinities. It was exported from 1867 onwards from Portugal to France, again with oysters in the polyp stage. This has probably allowed the spread to other European countries including the British Isles since France was a major oyster exporter (Edwards 1976). It can also disperse in the hydromedusae stage in water currents and ballast water.

Distribution

It has a patchy distribution around British coasts and, in a new area, is usually first noted in aquaria; it is also found on other western European coasts.

Factors likely to influence spread and distribution

Its spread is likely to have been influenced by movements of oysters, shipping and marginal spread of established populations.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

It is unlikely that the venom of *Gonionemus vertens* is as harmful to humans as in much studied *Gonionemus* populations of Far-Eastern Russian waters (see Cornelius (1995) and references therein).

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Acknowledgements (contributions from questionnaire)

Dr P.F.S. Cornelius, The Natural History Museum, London.

Clavopsella navis

Phylum:	Cnidaria
Class:	Hydrozoa
Order:	Athecata
Species name:	*Clavopsella navis* (Millard 1959)
Synonyms:	*Clavopsella quadrangularia* Thiel 1962, *Rhizorhagium navis* Millard 1959
Common name:	None

Date of introduction and origin

Clavopsella navis was first noted in 1973 (P.F.S. Cornelius pers. comm.) in Widewater Lagoon, Shoreham, West Sussex. Its origin is not known since it has only ever been found in the vicinity of ports and harbours, presumably as an introduction.

Method of introduction

It was probably transported on ships' hulls.

Reasons for success

Many hydroids are substrate generalists which probably assists in their distribution on ships and other slow-moving material as well as establishment upon arrival in foreign ports etc.

Rate of spread and methods involved

In Britain, *C. navis* is not known to have spread outside the one lagoon where it is found.

Distribution

Widewater Lagoon, West Sussex, contains the only known British population. Elsewhere in Europe it is known from the Kiel Canal, Germany, and the Azores. Outside Europe, it is only known from Cape Town harbour, South Africa (Barnes 1994). It is a brackish-water species.

Factors likely to influence spread and distribution

Its spread is likely to be influenced by slow-moving shipping entering brackish waters.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

None.

References

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Dr P.F.S. Cornelius, The Natural History Museum, London.

Haliplanella lineata

Phylum: Cnidaria
Class: Anthozoa
Order: Actinaria

Species name: *Haliplanella lineata* (Verrill 1869)
Synonyms: *Haliplanella luciae* (Verrill 1898); has also been placed in the genera *Sagartia*, *Diadumene* and *Aiptasiomorpha*
Common name: Orange-striped sea anemone

Date of introduction and origin

Haliplanella lineata is native to the Pacific. It was probably introduced from Japan into the Atlantic towards the end of the 19th century (Manuel 1988).

Method of introduction

It was probably carried on ships' hulls (Stephenson 1935; Gollasch & Riemann-Zürneck 1996), and transported on oysters or other shellfish.

Reasons for success

The adult anemone is the migrating phase; it shows extreme tolerance towards abiotic factors (Gollasch & Riemann-Zürneck 1996); and it can frequently reproduce by asexual, longitudinal fission and pedal laceration (Slick 1991).

Rate of spread and methods involved

It has an unknown rate of spread. Local colonisation is achieved by fission, and remote spread through transport on ships' hulls.

Distribution

It is distributed around Britain and throughout continental Europe (Stephenson, 1935 & Williams 1973), generally occurring in estuaries, ports and harbours on major shipping routes.

Factors likely to influence spread and distribution

Its distribution is likely to have been influenced by shipping. However, its extension into brackish water is limited by its tolerance of low salinities which, below 12‰ are ultimately lethal (Slick 1991). *Haliplanella lineata* seems to be associated almost exclusively with mussels or oysters, even on ships' hulls (Gollasch & Riemann-Zürneck 1996).

Effects on the environment

Unknown.

Effects on commercial interests

It can possibly be a nuisance as a fouling organism.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

The species is now a common brackish-water anemone in Britain (Barnes 1994).

References

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Nematoda

Anguillicola crassus

Phylum: Nematoda
Class: Dracunculoidea
Order: Anguillicolidae
Species name: *Anguillicola crassus* Kuwahara, Niimi & Itagaki 1974
Synonyms: None
Common name: Swim-bladder nematode

Date of introduction and origin

Anguillicola crassus was introduced to the European continent in the 1980s, where it was reported independently from Germany and Italy in 1982, having been introduced from East Asia (Koops & Hartmann 1989). It was introduced to England in 1987 (Kennedy & Fitch 1990) from continental Europe (Køie 1988).

Method of introduction

It was imported with infected Japanese eels *Anguilla japonica* into Europe; and with continental *Anguilla anguilla* to Britain.

Reasons for success

A variety of crustacean intermediate hosts and fish parasitic hosts are known for this parasitic swim-bladder nematode, increasing the chances of its survival. There is high resistance of the sheathed, second stage, larvae to adverse conditions (Kennedy & Fitch 1990), and the species showed an excellent colonising ability (Kennedy 1993). An absence of native swim-bladder nematodes is also a factor in the success of *A. crassus* as there is a lack of competitors and resistance of the host.

Rate of spread and methods involved

Once introduced into a lake or river, *Anguillicola crassus* may spread rapidly among the eel population. Levels of infestation have been recorded to rise from 10% to 50% within a year (Belpaire *et al*. 1989; Koops & Hartmann 1989). Spread within an aquatic system is generally through intermediate hosts and movements of other fish. Spread between localities is generally through transport of infected eels. *A. crassus* has been recorded in the open sea and in brackish coastal localities (Koops & Hartmann 1989; Mellergaard 1988). C.R. Kennedy (pers. comm.) has found it in lagoons in Italy at salinities up to 20‰.

Distribution

It is widespread in England, although not yet found in Scotland and Wales (Ashorth 1995). It is now found in most European countries (except Ireland) including in the Baltic Sea (Kennedy & Fitch 1990) and Iceland.

Factors likely to influence spread and distribution

Uncontrolled movement of infected eels will aid its spread.

Effects on the environment

Common eels *Anguilla anguilla*, if infected by *Anguillicola crassus*, can show adverse effects if the level of infestation is high. These include higher susceptibility to bacterial infections and death. The wall of the swim bladder may thicken and inflammation occur. Growth may slow and damage to the swim bladder may prevent the spawning migration to the western Atlantic (Køie 1988). Kennedy & Fitch (1990) document the occurrence of these effects in eels in British waters.

Effects on commercial interests

In eel farms the parasites have been observed to cause reduction in growth rate. The wall of the swim bladder of highly infected eels may burst (Mellergaard 1988).

Control methods used and effectiveness

No information is available.

Beneficial effects

None known.

Comments

This species is normally found in freshwater conditions, and brackish waters up to 20‰ salinity. However, it has been recorded in hosts in the open sea.

References

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Professor C.R. Kennedy, University of Exeter.

Annelida

Goniadella gracilis

Phylum: Annelida
Class: Polychaeta
Order: Phyllodocida (Glyceridae; glycerid)
Species name: *Goniadella gracilis* (Verrill 1873)
Synonyms: None
Common name: None

Date of introduction and origin

Goniadella gracilis was first recorded in 1970 in Liverpool Bay (Walker 1972). It was previously reported from North America (from where it was described) and South Africa. The species is likely to have been introduced from the east coast of the United States.

Method of introduction

The precise method of introductions is unknown, but is likely to have been ship-assisted. It is suspected that trans-Atlantic shipping carried it into Merseyside as ships frequently lie at anchor in Liverpool Bay before docking.

Reasons for success

Unknown.

Rate of spread and methods involved

Walker (1972) considered that it may have become quite common in Liverpool Bay only within the preceding 20 years. It has spread about 300 km (Mackie, Oliver & Rees 1995).

Distribution

It is widespread in the southern Irish Sea (Mackie, Oliver & Rees 1995). No other known European populations are known.

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

It appears that *Goniadella gracilis* has become quite common in Liverpool Bay in sandy gravel below 15 m water depth.

References

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Acknowledgements (contributions from questionnaire)

Dr A.S.Y. Mackie, National Museums and Galleries of Wales, Cardiff.

Marenzelleria viridis

Phylum:	Annelida
Class:	Polychaeta
Order:	Spionida (Spionidae; spionid)
Species:	*Marenzelleria viridis* (Verrill 1873)
Synonyms:	*Scolecolepis viridis* Verrill 1873, *Scolecolepides viridis* (Verrill 1873)
Common name:	None

Date of introduction and origin

Marenzelleria viridis was found in 1982 in the Firth of Forth (McLusky, Hull & Elliott 1993) and the Firth of Tay in 1984 (Atkins, Jones & Garwood 1987). It was first recorded on the European mainland coast in the Ems estuary (lying between Germany and The Netherlands) in 1983 (Essink & Kleef 1988). This species occurs naturally on the east coast of North America from where it was probably introduced.

Method of introduction

The species was probably transported as larvae and/or adults in ballast water. This theory is supported by collection of specimens in a plankton tow in a North American estuary (Maciolek 1984).

Reasons for success

Although the species has an exceptionally large reproductive potential (Sarda, Valiela & Foreman 1995) Atkins, Jones, & Garwood (1987) reported that in the period 1984-1986 recruitment occurred only once. There appear to be no recent data on reproduction in Britain.

Rate of spread and methods involved

Unknown.

Distribution

In the UK it has been found in the Firth of Forth, Firth of Tay and Humber estuary. It is also found in estuaries on the European side of the North Sea and in the Baltic (Essink & Kleef 1993; Bastrop, Röhner & Jürss 1995).

Factors likely to influence spread and distribution

Shipping may influence its spread

Effects on the environment

In the Tay, *M. viridis* occurred at greater sediment depths than other species in an intertidal mudflat, yet its distribution and population densities were negatively correlated with all other species (Atkins, Jones & Garwood 1987). In the Ems estuary in The Netherlands, increasing densities of *Marenzelleria viridis* in a sandy habitat coincided with a reduced abundance of the polychaete *Hediste diversicolor*, and density fluctuations of *M viridis* and the amphipod *Corophium volutator* showed a significant positive relationship (Essink & Kleef 1993). However, the cause of these effects is not understood, and may be environmental factors rather than species interactions. Recent studies in the Ems estuary by Essink, Eppinga & Dekker (in prep.) demonstrated an inverse abundance and biomass relationship between the introduced spionid polychaete *M. viridis* and the previously most abundant native polychaete *Hediste diversicolor*, indicating that competition occurs between the two species.

Effects on commercial interests

None.

Control methods used and effectiveness

None used.

Beneficial effects

None known in Britain. In the Ems, *M viridis* is preyed upon by plaice *Pleuronectes platessa* and flounder *Platichthys flesus* (Essink & Kleef 1993).

Comments

The biology of this species has been studied in the Tay estuary in Britain (Atkins, Jones & Garwood 1987) and various sites in mainland Europe, including the Ems estuary (Essink & Kleef 1993). There are also extensive studies (on the ecology, physiology, genetics, larval ecology and reproduction) of the species underway in German Baltic waters at the University of Rostock, Institute of Baltic Sea Research (K. Essink pers. comm.).

References

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Dr S. Atkins, Scottish Natural Heritage.
Dr K. Essink, National Institute for Coastal and Marine Management, The Netherlands

Clymenella torquata

Phylum:	Annelida
Class:	Polychaeta
Order:	Capitellida (Maldanidae, maldanid)
Species name:	*Clymenella torquata* (Leidy 1855)
Synonyms:	None
Common name:	Bamboo worm

Date of introduction and origin

Clymenella torquata was first recorded from Whitstable, Kent, in 1936 by Newell (1949a, 1949b; Pilgrim 1965). It was introduced as a consequence of trade from the western Atlantic between 1870 and 1936.

Method of introduction

It was introduced unintentionally in associated with the American oyster *Crassostrea virginica* to oyster grounds on the south-east coast of England (Newell 1954).

Reasons for success

Unknown.

Rate of spread and methods involved

It would not have appeared to have spread, except that a single adult specimen was recorded 5 km off the Northumberland coast in 1976.

Distribution

Still recorded from Whitstable in 1959 (Pilgrim 1965; Zibrowius & Thorp 1989) and also collected from Northumberland in 1976 by R. Bamber (pers. comm.).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

None.

Effects on commercial interests

None.

Control methods used and effectiveness

None used.

Beneficial effects

None.

Comments

Pilgrim (1965) commented that individuals collected from Whitstable were 15 cm long while those from Beaufort, North Carolina, USA, were only 6 cm long, but were otherwise the same.

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Acknowledgements (contributions from questionnaire)

Dr C. Mettam, University of Cardiff.

Hydroides dianthus

Phylum: Annelida
Class: Polychaeta
Order: Sabellida (Serpulidae, serpulid)
Species name: *Hydroides dianthus* (Verrill, 1873)
Synonyms: *Eupomatus dianthus*
Common name: A tubeworm

Date of introduction and origin

Hydroides dianthus was first recorded in 1970 at Hamble Spit, Southampton Water (Zibrowius 1978). This species originates from the east coast of North America and was probably introduced from there, or possibly from the Mediterranean, where it is widespread within harbours and lagoons (Zibrowius 1971).

Method of introduction

It was possibly introduced as a fouling organism, transported on ships hulls, and larvae could be transported in ballast water. There was possible additional introduction associated with the American oyster *Crassostrea virginica* (Zibrowius 1983; Zibrowius & Thorp 1989).

Reasons for success

While other species of the genus *Hydroides* together with *Ficopomatus enigmaticus* are likely to be limited in distribution by their temperature tolerances, there appears to be no similar restriction on *H. dianthus*. This species will experience similar conditions around British coasts to those prevailing throughout large parts of its native habitat along the eastern seaboard of North America. Accordingly, if it has not already done so, it is expected to spread widely (C.Thorp pers. comm.).

Rate of spread and methods involved

There has been no known spread of this species, despite predictions. The pattern of spread expected would be to mimic that within the Mediterranean, namely, to ports and lagoons through the vector of shipping (Zibrowius & Thorp 1989).

Distribution

Its current British distribution is limited to Southampton Water. This species is widespread in the Mediterranean and has been recorded from the Atlantic coasts of France and Spain (Zibrowius 1983).

Factors likely to influence spread and distribution

It only survives where there are good planktotrophic waters. Competition with other filter-feeders, particularly *H. ezoensis*, may influence its spread within Southampton Water.

Effects on the environment

Unknown.

Effects on commercial interests

It is a fouling organism. Nelson & Stauber (1940) reported that *Hydroides dianthus* may kill young oysters (*Crassostrea virginica*) by overgrowing them in its native area of eastern North America. It is also the host of certain nematode stages in eastern North America.

Control methods used and effectiveness

It can be removed by scraping of buoys and ships' hulls.

Beneficial effects

Its effects are negligible but see under *H. ezoensis* and *F. enigmaticus*.

Comments

While it is possible that *H. dianthus* has been present in British waters for some considerable time (Zibrowius & Thorp 1989), it is known from only a few specimens collected from Southampton Water (Thorp, Pyne & West 1987; Zibrowius & Thorp 1989).

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Acknowledgements (contributions from questionnaire)

Dr C.H. Thorp, University of Portsmouth.

Hydroides ezoensis

Phylum:	Annelida
Class:	Polychaeta
Order:	Sabellida (Serpulidae; serpulid)
Species name:	*Hydroides ezoensis* Okuda 1934
Synonyms:	None
Common name:	A tubeworm

Date of introduction and origin

Hydroides ezoensis was first recorded in 1976 in Southampton Water and is thought to have been introduced in that year (Thorp, Pyne & West 1987; Zibrowius & Thorp 1989) probably from Japan. It originates in Asia where it is found on the Japanese and east Chinese coasts, and the Russian coast of the Sea of Japan.

Method of introduction

Probably introduced on the hulls of Nissan and Datsun car transporters to Southampton, Hampshire, and possibly also in ballast water (C.H. Thorp pers. comm.).

Reasons for success

Its success in Southampton Water was due to high levels of phytoplankton and hot summers. This would have encouraged this suspension-feeding serpulid to grow rapidly and reproduce. Success is also possibly due to a lack of predators and favourable physical conditions, including long residence time of water in the dock. Southampton Water is dominated by phytoplankton populations which, in summer, may exceed those elsewhere in the Solent by a factor of three or four (Anon 1976; Williams 1980). 1976 witnessed an extraordinarily prolonged and hot summer with sufficient sunshine to maintain high levels of phytoplankton within Southampton Water. High levels of phytoplankton, coupled with elevated temperatures within Southampton Water, would have enabled this suspension-feeding serpulid both to grow rapidly and to reproduce. Crisp (1958) emphasised that Southampton Water, due to its enclosed nature and small tidal range, would exchange water very slowly with that of the Solent. The consequent 'retention' of water within Southampton Water could have contributed to a rapid build-up of the *H. ezoensis* population through retention of larvae, as Crisp (1958) suggested for the non-native barnacle *Elminius modestus*.

Rate of spread and methods involved

This species has not spread outside the Solent (Thorp, Pyne & West 1987; Zibrowius & Thorp 1989). It was introduced into France with *Crassostrea gigas* (Gruet, Héral & Robert 1976; Zibrowius 1978) but died out (Thorp, Pyne & West 1987).

Distribution

It is only found in the Solent area, including the harbours complex of Portsmouth, Langstone and Chichester. Outside of Southampton Water numbers are very small and, apart from a significant population at Cowes, Isle of Wight, comprise mostly single individuals with no aggregation. A dense fouling population on the hull of HMS *Cavalier*, transferred from Southampton Water to Brighton Marina in 1984, failed to reproduce and rapidly deteriorated (C.H. Thorp pers. comm.). The only other record in Europe was from the Atlantic coast of France (Gruet, Héral & Robert 1976; Zibrowius 1978) where *Hydroides ezoensis* was introduced with imported oyster spat from Japan. This introduction was very short-lived and apparently did not spread from the point of introduction (Thorp, Pyne & West 1987).

Factors likely to influence spread and distribution

It only survives where there are good planktotrophic waters and its failure to colonise Brighton Marina following transfer on a ship's hull may be due to insufficient food availability (Thorp, Pyne & West 1987). In its native Japanese waters *H.ezoensis* appears to require temperatures of approximately 20°C to spawn and settle (Miura & Kajihara 1984). However, its distribution suggests that lethal temperatures have little influence over the spread of the species. Thorp (1994) has shown for the serpulid *Ficopomatus enigmaticus* that even when minimum temperatures are reached, spawning may be delayed in the absence of adequate phytoplankton (Himmelman 1980).

Effects on the environment

It has unknown effects, although perhaps some displacement of 'waterline' green algae *Ulva* and *Enteromorpha* occurs (C.H. Thorp pers. comm.). It has not displaced the heavy sea-squirt-dominated fouling community at an immediately lower level.

Effects on commercial interests

It is a severe fouling organism on harbour structures and ships' hulls throughout Southampton Water. While this additional fouling load does not appear to have had any deleterious effect on fixed harbour structures, it has caused flotation problems of buoys and added considerably to fouling of poorly-protected ships.

Control methods used and effectiveness

It can be removed by scraping of buoys and ships' hulls.

Beneficial effects

It probably adds to the diversity and success of indigenous species. Within the bulk of its massive encrustations (30 cm thick (Thorp, Pyne & West 1987)) is a protected habitat for free-living and sessile invertebrates (C.H. Thorp pers. comm.). It provides food: the opercula and branchial crown are eaten by fish predators, and larvae and eggs are produced in very large numbers, food for filter-feeders (C.H. Thorp pers. comm.).

Comments

This massive introduction, initiated almost certainly in 1976, passed without comment until specimens were removed from the hull of a fouled tug in 1982. Although enquiries elicited the information that heavy tube-worm fouling had been observed in 1980, and perhaps earlier, it was only the 'accident' of a research student collecting fouling algae that brought the massive encrustations to light.

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Acknowledgements (contributions from questionnaire)

Dr C.H. Thorp, University of Portsmouth.

Ficopomatus enigmaticus

Phylum:	Annelida
Class:	Polychaeta
Order:	Sabellida (Serpulidae; serpulid)
Species name:	*Ficopomatus enigmaticus* (Fauvel 1923)
Synonyms:	*Mercierella enigmatica* Fauvel 1923
Common name:	A tubeworm

Date of introduction and origin

Ficopomatus enigmaticus was first noticed in northern France in 1921 (Fauvel 1923). It was first recorded from London docks in 1922 (Monro 1924). This origin of this species is not clear, it occurs in waters of variable salinity in temperate or warm temperate areas of both northern and southern hemispheres, and it was possibly introduced from Australia (Zibrowius & Thorp 1989). However, recent Australian literature lists *Ficopomatus enigmaticus* as introduced, and the best conclusion is that it is clearly southern hemisphere in origin (L. McCann & J. Carlton pers. comm.).

Method of introduction

Its preferred habitat within brackish waters, including estuaries, results in this species being ideal for transport on ships hulls (most major ports are sited on estuaries) and commercial mollusc shells.

Reasons for success

Within relatively confined waters of variable salinity it suffers little competition from other serpulids. Many estuaries are characteristically areas of high productivity and so filter-feeders such as *Ficopomatus enigmaticus*, which are able to stand considerable variations in salinity are well placed to reap the benefit. High fecundity, possibly allied with larval retention within semi-enclosed waters, facilitates a rapid build up of numbers and initially there might be an absence of predators.

Rate of spread and methods involved

Its disjunct distribution suggests spread by remote dispersal of mobile adults (on ships' hulls).

Distribution

Ficopomatus enigmaticus has been found in all ports from north Pembrokeshire to the Thames estuary (see reference list). Its distribution is, however, confined to coastal brackish waters and therefore disjunct. It has also been found in Barrow-in-Furness, Cumbria (Markowski 1962). This species is known to be widespread throughout Europe, including Ireland. Thorp (1994) reported how the Emsworth population, West Sussex experienced a catastrophic decline in 1986 and suggested that high density populations are liable to suffer periodic decline.

Factors likely to influence spread and distribution

It is thought to be at, or close to, its temperature minimum for maintaining populations and successful reproduction along southern coasts of Britain (Zibrowius & Thorp 1989; Thorp 1994). More northerly populations survive owing to artificially raised water temperatures. In addition, successful reproduction is considered to be limited to waters of variable salinity. In Britain, therefore, any future invasions or spread would be expected to be confined to brackish waters on southern coasts.

Effects on the environment

Its effects on native species are more likely to be beneficial than problematic (see below). This species favours waters which present some degree of stress to most open-shore marine organisms. Its requirement for variable-salinity water in which to spawn ensures that the major populations do not interfere with most indigenous species.

Effects on commercial interests

It is a fouling species which affects ships, buoys and harbour structures.

Control methods used and effectiveness

It is removed from buoys and ships' hulls by scraping.

Beneficial effects

While *F. enigmaticus* can be a fouling nuisance it can also benefit the waters it invades. As Keene (1980) and Davies, Stuart & Villiers (1989) have shown, the presence of large numbers in enclosed waters including marinas, where they would be considered a fouling nuisance, has had very beneficial effects on water quality, reducing suspended particulate loads and improving both the oxygen and nutrient status. Thomas & Thorp (1994) have also shown that a large population of *F. enigmaticus* can remove material from suspension and thus have a very beneficial effect on other benthic species within enclosed or semi-enclosed waters. However, abundant filter-feeders can also deplete phytoplanktonic resources and suspended particulate organic material which might otherwise be utilised by other, native, filter-feeders. Through production of faeces and psuedofaeces in large quanities they also concentrate contaminants from the water column and pass them into the sediment and hence up the food chain.

Comments

Recorded initially in 1937 from Weymouth Harbour, Dorset, and within adjacent Radipole Lake in 1952 (Tebble 1953, 1956), this species has been noted there on a number of widely separated occasions over subsequent years. Lack of data render it impossible to determine whether the population in 1937 had survived through many generations for more than 50 years, or whether its observed presence represents a series of discrete invasions, each of which lasted a finite period.

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Acknowledgements (contributions from questionnaire)

Dr C.H. Thorp, University of Portsmouth.

Janua brasiliensis

Phylum:	Annelida
Class:	Polychaeta
Order:	Sabellida (spirorbid)
Species name:	*Janua brasiliensis* (Grube 1872)
Synonyms:	*Neodexiospira brasiliensis, Dexiospira brasiliensis*
Common name:	A tubeworm

Date of introduction and origin

Janua brasiliensis is suggested to have been introduced into Portsmouth Harbour, the Solent, in 1974 (Knight-Jones *et al.* 1975), possibly from Brazil (Zibrowius & Thorp 1989). This species is widespread in tropical areas, including Brazil.

Method of introduction

One possible method of transport was on ships' hulls (Zibrowius & Thorp 1989) from the Round the World Yacht Race - the previous stop of the race was Brazil. Another possible method of introduction was as epiphytes on *Sargassum muticum* (Critchley *et al*. 1990).

Reasons for success

Unknown.

Rate of spread and methods involved

No spread has been recorded in British waters. While marginal dispersal is unlikely through the brief, motile, larval stage (Knight-Jones & Knight-Jones 1980), remote dispersal could be expected by adults attached to drifting *Sargassum muticum*. Spread is also conceivable as a fouling organism on ships' hulls, however, its isolated location in Britain suggests this has not occurred in British waters.

Distribution

This species, although widespread in tropical areas, has a very limited distribution in Europe; in the UK it is limited to Portsmouth Harbour; and elsewhere in Europe it is reported from the Oosterschelde, The Netherlands (Critchley & Thorp 1985), and St. Helier, Jersey (C.H. Thorp pers. comm.).

Factors likely to influence spread and distribution

This species' epiphytic association with the invasive brown alga *Sargassum muticum* provides it with a convenient vehicle for dispersal. *Sargassum muticum* is noted for its habit of casting off lateral branches in late summer and early autumn which, buoyed up with air bladders, are free to drift in surface currents over long distances. Such drifting plants could transport an 'innoculum' of attached *Janua brasiliensis*. Elsewhere in Europe, in both the Goes Canal (Eastern Scheldt) and Havre des Pas (Jersey), records of *Janua brasiliensis* are from sites where *Sargassum muticum* had already been recorded (Critchley, Farnham & Morrell 1983). *Janua brasiliensis* reaches maturity within a single season and, additionally, has a reduced brooding period for its embryos in higher temperatures (Gray 1978). It would appear that while the means are available for *J. brasiliensis* to be as widely distributed as its *Sargassum* host, its limited occurrence within temperate waters may be determined by the availability of waters of suitable temperature. Elevated water temperatures in enclosed or semi-enclosed systems, such as Portsmouth Harbour, are likely to be a significant factor contributing to its success. In Portsmouth Harbour *Janua brasiliensis* exhibits a marked settlement preference for *S. muticum* in contrast to the submerged pontoon surfaces. It is notable that elsewhere in Europe, *J. brasiliensis* has become more successful on native host plants, in the form of *Zostera* at Goes (Critchley & Thorp 1985), and *Fucus serratus* at Havre des Pas (C.H. Thorp pers. comm.).

Effects on the environment

In the Goes Canal the density of the settlement of *J. brasiliensis* on the eel grass *Zostera* was great enough to have weighed down leaves such that lay on the canal sediment. This considerably impaired the eel grass' photosynthetic efficiency (Critchley & Thorp 1985).

Effects on commercial interests

It is a fouling organism but has negligible effect in British waters.

Control methods used and effectiveness

Not applicable to such a small animal.

Beneficial effects

None known.

Comments

All three records of *J. brasiliensis* from European waters have come about as a consequence of monitoring the spread of *S. muticum*, in the case of the Goes record in particular. It is possible that there are other sites with isolated populations on Channel coasts, both French and English, which have not been visited by competent 'spirorbidologists'. Such sites would be situated in the vicinity of warmed water, coastal power plants etc.

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Acknowledgements (contributions from questionnaire)

Dr C.H. Thorp, University of Portsmouth.

Pileolaria berkeleyana

Phylum:	Annelida
Class:	Polychaeta
Order:	Sabellida (spirorbid)
Species name:	*Pileolaria berkeleyana* (Rioja 1942)
Synonyms:	Currently the taxonomy of this genus is being reconsidered and it is likely that *Pileolaria rosepigmentata* (Uchida 1971) will be reinstated as a species separate from *Pileolaria berkeleyana* (Rioja 1942). Thus, the population present in British waters will revert to its previously cited name of *P. rosepigmentata*.
Common name:	A tubeworm

Date of introduction and origin

Pileolaria berkeleyana was first recorded from Portsmouth Harbour in The Solent by the name *P. rosepigmentata* in 1974 (Knight-Jones *et al.* 1975). The date of the introduction is unknown but it is thought to have been introduced from Japan. Outside Britain the known distribution of *P. rosepigmentata* is around Japan and the Kamchatka Peninsula. *P. berkeleyana* is known from all oceans except the Arctic.

Method of introduction

While it is possible that this species was introduced with the Japanese seaweed *Sargassum muticum*, its noted preference for a hard substratum for settlement (Gray 1978) suggests that it is more likely to have arrived on ships' hulls as a fouling organism (Zibrowius & Thorp 1989).

Reasons for success

Unknown.

Rate of spread and methods involved

Its spread has not been rapid. Its distribution at quite widely separated sites, each of which is a port, suggests that dispersal has been 'remote', probably as fouling on boat hulls. The record of a single specimen on *S. muticum* at St. Helier, Jersey, and its original record from *S. muticum* in Portsmouth Harbour suggest that, despite its preference for hard substrata, *S. muticum* could serve as an additional vector.

Distribution

Currently recorded from Falmouth (Cornwall), Plymouth (Devon) and Portsmouth (Hampshire) in the UK (Thorp, Knight-Jones & Knight-Jones 1986). It has not been recorded as established from elsewhere in Europe with any certainty: a single specimen, epiphytic on *Sargassum muticum*, was recorded from St. Helier, Jersey.

Factors likely to influence spread and distribution

Its presence in ports, together with its preference for hard substrata for settlement, furnish this species with the potential to spread through the agency of ship fouling (Gray 1978). Studies of its reproductive biology suggest that the adult worm has the ability both to survive and reproduce in a wide range of temperatures (Thorp 1991). Thus, this species should be able to survive in northern European waters without the need for any artificial warming.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None warranted on such a small animal.

Beneficial effects

None known.

Comments

This species, like *Janua brasiliensis*, has been recorded only through the monitoring of the non-native alga *S. muticum*, and it is therefore likely that there are other sites where this species is present but has not been recorded. In fact, C.H. Thorp (pers. comm.) considers it is likely that this species has spread more widely than *J. brasiliensis*.

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Acknowledgements (contributions from questionnaire)

Dr C.H. Thorp, University of Portsmouth.

Chelicerata

Ammothea hilgendorfi

Phylum:	Chelicerata
Class:	Pycnogonida
Order:	------
Species name:	*Ammothea hilgendorfi* (Böhm 1879)
Synonyms:	*Leionymphon hilgendorfi* Böhm 1879
Common name:	A sea spider

Date of introduction and origin

Ammothea hilgendorfi was first observed in 1978 in Southampton Water (Bamber 1985). This species is thought to have been introduced from Japan. It originates in the tropical and temperate North Pacific littoral zone of south-east Asia.

Method of introduction

It is transported on ships' hulls.

Reasons for success

Unknown.

Rate of spread and methods involved

Rate of spread is minimal without assistance from man (R.N. Bamber pers. comm.).

Distribution

Currently it is known in Britain only from Southampton Water (Bamber 1988). Elsewhere in Europe it has been found in a lagoon in Venice.

Factors likely to influence spread and distribution

There is no dispersive phase in the species' life cycle which means dispersal is very slow.

Effects on the environment

None.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None.

Beneficial effects

None known.

Comments

This is a species of no ecological or commercial significance. Introduction to the lagoon in Venice is also presumed to have been on a ship's hull.

Chocolate brown markings on the trunk and legs (as indicated in the illustration) are a useful aid to identification.

References

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Acknowledgements (contributions from questionnaire)

Dr R.N. Bamber, Aquatic Research Laboratories Ltd, Southampton.

Crustacea

Elminius modestus

Phylum:	Crustacea
Class:	Maxillopoda
Order:	Thoracica
Species name:	*Elminius modestus* Darwin 1854
Synonyms:	None
Common name:	None

Date of introduction and origin

Elminius modestus was first found in Chichester Harbour, Hampshire, in 1945 where it is believed to have arrived sometime between 1940 and 1943 (Bishop 1947; Crisp 1958). This species naturally occurs in Australasia and was introduced from Australia or New Zealand (Crisp 1958).

Method of introduction

It is transported on ships' hulls or possibly on flying boats (M. Barnes pers. comm.). There is also possible transport of pelagic larvae in ballast water.

Reasons for success

Elminius modestus grows rapidly and it withstands reduced salinity, turbid waters, lower temperatures than the native barnacles *Chthamalus* spp. and higher temperatures than the native barnacles *Balanus* spp. Its initial growth rate can be 6 mm in 40 days and it reaches maturity in its first season. It produces several broods per year (*Semibalanus balanoides* only produces one brood per year and earlier in the season). It can grow both high up the shore and in the sublittoral.

Rate of spread and methods involved

It has a fairly rapid rate of spread (Crisp, 1958). This involves marginal transport through pelagic larval dispersal and remote dispersal through adult transport on ships' hulls Crisp (1958). See Crisp (1958) for patterns of spread around Britain between 1940 and 1960, in which time it spread from Southampton Water to the borders of Scotland. This species spread from Chichester Harbour to Shetland in 38 years. It arrived in Shetland by remote dispersal (Hiscock, Hiscock & Baker 1978) but by 1986 it could not be found there.

Distribution

This barnacle is distributed all around the British mainland coast (Crisp 1958, Collins 1959). It has also recently been reported from the Outer Hebrides (Howson, Connor & Holt 1994). It is found on the Atlantic coasts of Europe from Germany to Gibraltar (Barnes & Barnes 1966).

Factors likely to influence spread and distribution

Shipping is very likely to effect remote dispersal. Low water temperature is likely to restrict northwards spread of this species. Barnes & Barnes (1960) described how *Elminius* increased considerably in abundance in the Clyde only following the warm summer of 1959.

Effects on the environment

In northern areas, such s the British Isles, *Elminius modestus* competes with *Semibalanus balanoides* (Crisp 1958), whereas in southern Europe it competes with *Chthamalus* species as well. *E. modestus* is, however, also found in low or variable salinity habitats where native *S. balanoides* does not survive. *Balanus improvisus* seems to be retreating where it is in competition with *E. modestus* (Crisp 1958; Hayward & Ryland 1990). *Balanus improvisus* may have been displaced from the Tamar estuary, Devon and Cornwall, and become extremely rare in the Dart, Devon, as a result of competition from *E. modestus* (A. Southward pers. comm.). It has been suggested that since it produces a larger number of larval stages in the summer than *S. balanoides*, it may be in direct competition with other components of the zooplankton, notably the larval stages of other benthic species (Crisp 1958; Farnham 1980).

Effects on commercial interests

It is a fouling organism in favourable conditions.

Control methods used and effectiveness

Ships' hulls and buoys are scraped to remove barnacles.

Beneficial effects

None known.

Comments

None.

References

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Acknowledgements (contributions from questionnaire)

Dr M. Barnes, Dunstaffnage Marine Laboratory.

Balanus amphitrite

Phylum:	Crustacea
Class:	Maxillopoda
Order:	Thoracica
Species name:	*Balanus amphitrite* Darwin 1854
Synonyms:	None
Common name:	None

Date of introduction and origin

Balanus amphitrite was found in 1937 in Shoreham Harbour, Sussex (Bishop 1950). This barnacle is tropical. On the basis of fossil records, it is considered to be native to the southwestern Pacific and Indian Oceans, and to have been introduced to the North Pacific and Atlantic Oceans, for which no fossil records exist.

Method of introduction

It may have been transported to Britain in the adult stage as a fouling organisms on ships' hulls, or the pelagic larvae may have travelled in ballast water.

Reasons for success

Its establishment may have been helped by warm waters from power stations.

Rate of spread and methods involved

Unknown.

Distribution

Populations have been found in southern England, southern Wales and throughout European countries south of Britain. *Balanus amphitrite* has also been recorded from Shetland in 1988 although a breeding population is apparently not established there (S.M. Smith pers. comm.).

Factors likely to influence spread and distribution

Temperatures further north than southern England are too low for reproduction. It is at its northern limit in southern Britain.

Effects on the environment

Unknown.

Effects on commercial interests

It is a fouling organism.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

References

Bishop, M.W.H. 1950. Distribution of *Balanus amphitrite* Darwin var. *denticulata* (Broch). *Nature*, *165*: 409.

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Acknowledgements (contributions from questionnaire)

Dr M. Barnes, Dunstaffnage Marine Laboratory.

Acartia tonsa

Phylum:	Crustacea
Class:	Maxillopoda
Order:	Calanoida
Species name:	*Acartia tonsa* Dana 1848
Synonyms:	None
Common name:	None

Date of introduction and origin

Acartia tonsa was first recorded from Southampton Water by between 1916 and 1956 Conover (1957). This copepod was first reported in France by Remy (1927). It was previously known from the western Atlantic and Indo-Pacific coasts although it is not known from where it was introduced.

Method of introduction

It was possibly introduced through transport on ships hulls and/or in ballast waters (Remy 1927).

Reasons for success

Tolerance of low salinities found in estuaries will have contributed to its success.

Rate of spread and methods involved

Not known.

Distribution

In Britain this species has been found in Southampton Water (Conover 1957), the Tamar estuary, Devon and Cornwall, the Exe estuary in Devon (J.A. Lindley pers. comm.) and the Firth of Forth (Taylor 1987). European populations occur from Normandy to the Gulf of Finland (Brylinski 1981).

Factors likely to influence spread and distribution

Its distribution will be influenced by shipping as it occurs in estuarine sites of less than 33‰ salinity, which are also of higher temperatures than off-shore waters and provide the temperatures required for reproduction.

Effects on the environment

Unknown.

Effects on commercial interests

None.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

This species produces diapause eggs (Zilhoux & Gonzalez 1972) which may have helped with transport in ballast waters.

References

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Acknowledgements (contributions from questionnaire)

J.A. Lindley, Plymouth Marine Laboratory.

Eusarsiella zostericola

Phylum:	Crustacea
Class:	Ostracoda
Order:	Myodocopa
Species name:	*Eusarsiella zostericola* (Cushman 1906)
Synonyms:	*Sarsiella zostericola* Cushman 1906
Common name:	None

Date of introduction and origin

Eusarsiella zostericola was introduced into south-east English estuaries between 1870 and 1940 with trade from the USA Atlantic coast (Bamber 1987a & b; Kornicker 1975).

Method of introduction

It was introduced unintentionally in associated with the American oyster *Crassostrea virginica.*

Reasons for success

Unknown

Rate of spread and methods involved

The species has a low rate of dispersal, mainly by benthic adults which are capable of swimming.

Distribution

It is found in the Blackwater estuary in Essex and Medway estuary in Kent (Bamber 1987b), the Thames estuary and the Solent. No other European populations have been recorded.

Factors likely to influence spread and distribution

The species of ostracod has little dispersal ability; the juveniles are non-dispersive.

Effects on the environment

No effects known.

Effects on commercial interests

None.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

It is one of the many species introduced with American oysters. It is probably present in other estuaries, but as it is not present in British keys it is likely to be mis-identified or not identified. Although it is small in size, yet will be retained on 0.5 mm sieves, it is larger and more fecund than those of studied North American populations (Bamber 1987b).

References

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Acknowledgements (contributions from questionnaire)

Dr R.N. Bamber, Aquatic Research Laboratories Ltd, Southampton.

Dr J. Whittaker, The Natural History Museum, London.

Corophium sextonae

Phylum:	Crustacea
Class:	Eumalacostraca
Order:	Amphipoda
Species name:	*Corophium sextonae* Crawford 1937
Synonyms:	None
Common name:	None

Date of introduction and origin

Corophium sextonae was first introduced into Plymouth, Devon, in the 1930s (Crawford 1937) from New Zealand (Hurley 1954). A secondary introduction to Ireland occurred by the late 1970s or early 1980s (Costello 1993). This species naturally occurs in New Zealand.

Method of introduction

Unknown.

Reasons for success

Unknown.

Rate of spread and methods involved

Details of its spread are unknown, but there was possible natural spread from UK to Ireland (M. Costello pers. comm.).

Distribution

It is found in the southern and western British Isles (Moore 1978), north to Scotland. Its distribution elsewhere in Europe is not clear, however, it is found in Ireland (Costello *et al.* 1989; Costello & Kelly 1991).

Factors likely to influence spread and distribution

These are unknown, but possibly temperature is important.

Effects on the environment

It has apparently negligible effects, although Spooner (1951) considered that its increase in abundance in the Plymouth area was linked to a decrease in abundance of the native *Corophium bonnellii* (not used for other sp.).

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

None

References

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Acknowledgements (contributions from questionnaire)

Dr M.J. Costello, University of Dublin.

Eriocheir sinensis

Phylum:	Crustacea
Class:	Eumalacostraca
Order:	Decapoda
Species name:	*Eriocheir sinensis* H. Milne Edwards 1854
Synonyms:	None
Common name:	Chinese mitten crab

Date of introduction and origin

Eriocheir sinensis was most likely introduced from the Low Countries of Europe. It was first collected in Germany in 1912 (Clark 1986). The date of introduction to Britain is thought to be 1935 and this species was first introduced into the Thames at Chelsea in Greater London (Ingle 1986) and later to the Humber catchment in Yorkshire. This species' natural range is south-east Asia where it is found from China (26°N) to the Korean Peninsula (40°N) and Japan.

Method of introduction

This species may have been introduced by transport of small crabs or larvae in ballast water or through transport of adult crabs clinging to ships' hulls. Introduction may have been associated with scrap-metal yards on the Thames and Medway in Essex, and barges from the continent (P.F. Clark pers. comm.).

Reasons for success

Unknown.

Rate of spread and methods involved

Its dispersal is likely to be through pelagic larvae and mobile adults; the rate of spread is not known.

Distribution

In Britain this species occurs in the Humber, Thames and Medway estuaries (Clark 1986). It has also been reported specifically from the River Ancholme, a tributary of the Humber since 1976, and the River Wharfe and River Ouse in Yorkshire since 1986, where it is caught in nets laid by eel fishermen (B. Helmsley-Flint pers. comm.). European populations can be found from Finland to France (Ingle 1986).

Factors likely to influence spread and distribution

Currents may take the larvae onto the coasts of Europe. This species may be preyed on by pike *Esox lucius*, eels *Anguilla anguilla* and brown trout *Salmo trutta* (P.F. Clark pers. comm.). Limited reproductive success may be a limiting factor to its spread in Britain.

Effects on the environment

For most of its life *E. sinensis* lives in fresh water. During August adult crabs migrate seawards and gather in large swarms to breed in estuaries (Panning 1939). When population densities are high, *E. sinensis* causes considerable damage to soft sediment banks through burrowing which increases erosion and might affect flood defences. This species is an intermediate host for the mammalian lung fluke *Paragonimus ringer*.

Effects on commercial interests

It may damage the nets of eel fishermen. Damage caused to river banks may increase repair costs.

Control methods used and effectiveness

Those caught in eel nets are destroyed. It may be possible to use biological control through maintenance of fish populations leading to increased predation.

Beneficial effects

Parasite-free individuals, have a small commercial value: In the Japanese restaurant market *E. sinensis* was worth £20/kg in 1995.

Comments

Increases in population in the Thames in recent years may be attributable to drought conditions during 1989-1992 having facilitated greater settlement of young crabs (Atrill & Thomas in press). Adults occupy an essentially freshwater habitat but must migrate to mate and release larvae in the saline mouths of estuaries, congregating as they do so. Young crabs in turn migrate up estuaries (Barnes 1994).

References

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P.F. Clark, Natural History Museum, London.

B. Helmsley-Flint, The Environment Agency, Northumbria and Yorkshire Region.

Rhithropanopeus harrisii

Phylum:	Crustacea
Class:	Eumalacostraca
Order:	Decapoda
Species name:	*Rhithropanopeus harrisii* (Gould, 1841)
Synonyms:	*Pilumnus harrisii* Gould 1841, *Pilumnus tridentatus* Maitland 1874, *Heteropanope tridentata* Tesch 1922.
Common name:	Zuiderzee crab, dwarf crab

Date of introduction and origin

Rhithropanopeus harrisii was first found in Roath Docks, Cardiff, South Wales, in 1996. It is not known where the introduction came from, although this species is native to the east coast of the American continent from New Brunswick to north-east Brazil (Christiansen 1969).

Method of introduction

The method of introduction to Britain is unknown but was probably in association with ships, possibly in ballast water or clinging to hulls. Ships arrive in Cardiff Docks from all over the world, including coal barges from the U.S.A. It was first observed in Europe in the Zuiderzee, The Netherlands and Christiansen (1969) consider it probably arrived in the ballast or on the hulls of ships.

Reasons for success

Its reason for success is unknown. However, the dock water in which *Rhithropanopeus harrisii* has been found is of low salinity (about 12‰).

Rate of spread and methods involved

Rhithropanopeus harrisii spread through much of continental Europe between the 1870s and 1950s (Christiansen 1969). However, it has only very recently arrived in Britain. Its spread in Britain is unknown, and so far it has not been found outside Cardiff Docks. Its spread is probably associated with shipping.

Distribution

In Britain this species has only been recorded as established throughout Cardiff Docks. Elsewhere in Europe it is found in Denmark, Belgium, The Netherlands (where it is much less common than previously), Poland, West Germany and France, and in Russia, Romania and Bulgaria - from the Black and Caspian Seas and also in the Sea of Azov (Christiansen 1969).

Factors likely to influence spread and distribution

Shipping routes are likely to affect the spread and distribution of this species.

Effects on the environment

Unknown

Effects on commercial interests

Unknown

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Cardiff Docks harbour other non-native species, including the tube worm *Ficopomatus enigmaticus*, with which *R.. harrisii* may associate, possibly on trophic levels.

References

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Acknowledgements (contributions from questionnaire)

Dr C. Mettam, University of Cardiff.

P.F. Clark, Natural History Museum, London.

Mollusca

Crepidula fornicata

Phylum:	Mollusca
Class:	Gastropoda
Order:	Mesogastropoda
Species name:	*Crepidula fornicata* (Linnaeus 1758)
Synonyms:	None
Common name:	Slipper limpet

Date of introduction and origin

The first known occurrence of *Crepidula fornicata* in Europe was in 1872 in Liverpool Bay, but populations in this area have since died out. *Crepidula fornicata* is known to have been introduced to Essex between 1887 and 1890 from North America (Loosanoff 1955; Crouch 1894, 1895; Orton 1912; Fretter & Graham 1981).

Method of introduction

The individuals in Essex from which the spread of *Crepidula* started were introduced in association with imported American oysters *Crassostrea virginica*. This species may also be transported on ships' hulls (Franklin & Pickett 1974), and in ballast water in the pelagic larval phase. Historic populations (now extinct) have also been introduced in association with the American hard shelled clam *Mercenaria mercenaria* (McMillan 1938; Minchin McGrath & Duggan 1995).

Reasons for success

Its success is probably due to a lack of predators and the unusual method of reproduction (which relies upon individuals settling upon each other and reproduction thus being assited through their close proximity); and a pelagic larval stage aids the spread once introduced.

Rate of spread and methods involved

It showed fairly rapid spread (Franklin & Pickett 1974), from Essex to Weymouth, Dorset by 1945 (Seaward 1987), and by the early 1950s its range had extended to Northumberland (see Minchin, McGrath & Duggan 1995).

Distribution

This species is found in southwest, south and southeast Britain and as far north as Pembrokeshire on the west coast and Yorkshire on the east coast (Hancock 1969; Utting & Spencer 1992; Spencer 1990; Smith 1995; Chipperfield 1951). It does not occur in any abundance deeper than 30 metres (Barnes, Coughlan & Holmes 1973). It also occurs off mainland Europe, as far north as southern Norway on the Skagerak coast.

Factors likely to influence spread and distribution

Minimum winter temperatures may be important in limiting the ability to develop extensive populations in the north of Britain (Minchin, McGrath & Duggan 1995).

Effects on the environment

It competes with other filter-feeding invertebrates for food and space, and in waters of high concentrations of suspended material it encourages deposition of mud owing to the accumulation of faeces and pseudofaeces (Barnes, Coughlan & Holmes 1973).

Effects on commercial interests

It is considered a pest on commercial oyster beds, competing for space and food, while depositing mud on them (Utting & Spencer 1992) and the mud rendering the substratum unsuitable for the settlement of spat (Barnes, Coughlan & Holmes 1973). In parts of Essex slipper limpets were said to far exceed oysters in abundance (Walne 1956).

Control methods used and effectiveness

Dipping infested culch and oysters in saturated solutions of brine for a short period (Hancock 1969; Franklin 1974) is the cheapest, safest and most effective method of control. For clearance of large beds, dredging and disposal above high water mark has been applied (Hancock 1969).

Beneficial effects

It has been suggested that the shells may be used as oyster culch for spatfalls in the Solent (Barnes, Coughlan & Holmes 1973).

Comments

It is thought to have been introduced to France with oysters from England. It has attained dense concentrations of up to 1750 m^{-2} and in some areas has been the dominant member of the macrofauna (Seaward 1987).

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Urosalpinx cinerea

Phylum:	Mollusca
Class:	Gastropoda
Order:	Neogastropoda
Species name:	*Urosalpinx cinerea* (Say 1822)
Synonyms:	None
Common name:	American oyster drill, American tingle, American whelk tingle

Date of introduction and origin

Urosalpinx cinerea was first recorded from the Essex oyster grounds in 1927 by Orton & Winckworth (1928) who believed that it was probably introduced about 1900 from the east coast of the USA where it occurs naturally.

Method of introduction

It was an associated unintentional introduction with American oysters *Crassostrea virginica*.

Reasons for success

It found a plentiful food supply on the oyster beds.

Rate of spread and methods involved

It has shown slow and limited natural dispersal; movement has been facilitated through trade in oysters (Cole 1942).

Distribution

It is found on the Essex and Kent coasts, especially in the estuaries (Hancock 1959; Franklin & Pickett 1974). It has been severely affected by tributyl tin (TBT) pollution. It has not been found intertidally in East Anglia since 1991 (J. Light & I. Killeen pers. comm.). However, live specimens and egg cases continue to occur amongst oysters collected outside the Blackwater and Crouch estuaries, Essex, in deeper water offshore (B.E. Spencer pers. comm.). Some breeding enclaves may still survive off Whitstable, (Gibbs, Spencer & Pascoe 1991). It has not been recorded from other sites in England where American oysters were deposited. It is not known to occur in the rest of Europe (MAFF pers. comm.).

Factors likely to influence spread and distribution

Its limited adult mobility and lack of a free-swimming larval stage prevents it spreading quickly (Gibbs, Spencer & Pascoe 1991). A susceptibility to TBT and development of the debilitating condition known as 'imposex' has depleted populations on the Essex oyster beds since the early 1970s (Gibbs, Spencer & Pascoe 1991).

Effects on the environment

It predates native oysters; each individual consumes about 40 oyster spat (5-20 mm diameter) per year (Hancock 1954).

Effects on commercial interests

It devastates commercial oyster beds through predation.

Control methods used and effectiveness

'Tile traps' have been used during the summer to control this species (MAFF pers. comm.). On the Essex oyster beds at least, bounty was paid for bucket loads of *U. cinerea* (P. French pers. comm.).

Beneficial effects

None known.

Comments

None.

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Acknowledgements:

Dr P.E. Gibbs, Plymouth Marine Laboratory.

B.E. Spencer, Ministry of Agriculture, Fisheries and Food, Conwy.

Potamopyrgus antipodarum

Phylum:	Mollusca
Class:	Gastropoda
Order:	Mesogastropoda
Species name:	*Potamopyrgus antipodarum* (Gray, 1843)
Synonyms:	*Hydrobia jenkinsi* E.A. Smith, 1889, *Potamopyrgus jenkinsi* (E.A. Smith, 1889).
Common name:	Jenkin's spire shell

Date of introduction and origin

Potamopyrgus antipodarum was probably introduced as early as 1859 (D. Heppell pers. comm.). It was first recognised in Europe (as *Hydrobia jenkinsi*) by Smith (1889) from Plumstead, Beeton and Erith, in the Thames estuary, England. Earlier introductions may not, however, have become established, and it is considered that the Thames introduction is the source of the population in Britain. This species originates in New Zealand from whence it was introduced into Australia. It was introduced to Britain from southern Australia or Tasmania (Ponder 1988).

Method of introduction

It was introduced in drinking water barrels in ships from Australia (Ponder 1988). The snails were probably liberated while washing or filling water barrels or tanks and, because they can survive in brackish water, they could probably survive liberation into estuarine areas such as the River Thames.

Reasons for success

This species can reproduce rapidly parthenogenically. It thrives in freshwater and has become the most common freshwater gastropod in Britain.

Rate of spread and methods involved

Its rate of spread around the coast was moderate, however, once it started colonising freshwater habitats around 1904 (Castell 1962), it spread very rapidly. Firstly along major rivers and canals, then filling in the smaller streams and ditches etc. until, by 1920, it was very widespread in Britain.

Distribution

It is found in saline lagoon and brackish water ditches around Britain. Its distribution in freshwater extends from Shetland to the Isles of Scilly although in much of mainland Scotland it is confined to coastal areas. It had reached the European mainland (probably from Great Britain) by 1900 and is now widespread there (Wallace 1985).

Factors likely to influence spread and distribution

Its success in freshwater has led to its spread along water courses thus greatly extending its range.

Effects on the environment

Unknown other than it eats water cress but that is not a concern as this snail is so small.

Effects on commercial interests

In the early 1900s it was reported to be choking up London's fresh water supply (Castell 1962), however, the use of filters overcame this problem.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

This species is known from southern Australia and Tasmania. Ponder (1988) gives evidence to support the hypothesis that it is an introduction there from New Zealand, by European man or birds (the genus has diversified in New Zealand, but there is no evidence of this in Australia). Earliest known dates for Australian introductions are: Hobart area, Tasmania - 1872; Melbourne area, Victoria - 1895; Adelaide area, South Australia - 1926; Sydney area, New South Wales - 1963.

It was noted in 1889 that it was found in Tasmania "in the River Tamar and other places within the influence of salt water".

In the Sydney area *Potamopyrgus* has bred in freshwater tanks and reservoirs and has even been distributed through water pipes to emerge from domestic taps. In South Australia it has blocked water pipes and meters. It was probably first introduced to Tasmania by way of drinking water supplies on ships and probably entered Europe at about the same time in the same way.

The spread of *Potamopyrgus* further north into New South Wales may possibly be limited by high water temperatures, as it has been shown that New Zealand and European populations cannot tolerate a water temperature of more than about 28°C.

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Acknowledgements (contributions from questionnaire)

Dr David Heppell, Curator of Mollusca, National Museums of Scotland.

Crassostrea gigas

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Ostreoida
Species name:	*Crassostrea gigas* (Thunberg 1793)
Synonyms:	*Crassostrea angulata* (Lamarck 1819)
Common name:	Pacific oyster, Portuguese oyster

Date of introduction and origin

Crassostrea gigas was first introduced from Portugal into the River Blackwater, Essex, in 1926 (Utting & Spencer 1992). This colony was thought to have died out in 1965 because importations had ceased in 1962, but there was still a substantial population in the River Blackwater in 1970 (R. Mitchell pers. comm.). It was re-introduced in 1965 to Conwy, North Wales (MAFF quarantine) from the USA and British Columbia (Walne 1971; Walne & Helm 1979). This species occurs naturally in Japan and south-east Asia.

Method of introduction

It arrived through deliberate commercial introduction.

Reasons for success

It is most successful in commercial cultivation of hatchery-produced seed; over 30 years of extensive cultivation has provided opportunities for establishment in the wild.

Rate of spread and methods involved

It spreads through placement of hatchery-produced seed. Furthermore, local spatfall occurred in the River Blackwater, Essex, and light spatfalls registered in some estuaries of south-west England (Dart, Teign and Exe) and the Menai Strait following unusually warm summers in 1989 and 1990 (Spencer *et al.* 1994). Genetic evidence shows that spatfall in the River Teign originated from French stock (Child, Papageorgiou & Beaumont 1995), although it is unclear whether this was from adult specimens discarded at English sites or from larvae that crossed from the French side of the channel. Should the latter be the case, it would appear that, under favourable conditions for larval development, *Crassostrea gigas* has the capacity to spread substantial distances.

Distribution

It is distributed throughout England, Scotland, Wales and Ireland, and widely in Europe (France, Belgium, The Netherlands, Germany, Spain, Portugal, Denmark and Norway). Fisheries are sustained by natural spatfalls in The Netherlands and France.

Factors likely to influence spread and distribution

High temperatures are required for spawning and for larval development. Food required for developing larvae, and the presence of predators, especially shore crabs, can influence its spread (S.D. Utting pers. comm.).

Effects on the environment

No effects are recognised in Europe. In North America it has been known to settle in dense aggregations, excluding other intertidal species.

Effects on commercial interests

This species is cultivated widely as it is eaten.

Control methods used and effectiveness

None used.

Beneficial effects

Its presence benefits commercial oyster farming interests.

Comments

Crassostrea gigas and *Crassostrea angulata* are thought to be the same species and have been treated as such here (see e.g. Smith, Heppell & Picton in prep.). The only remaining population referred to as '*angulata*' in Britain is a brood stock kept by MAFF in the Menai Strait. Populations of adult Pacific oysters may persist for years. *Crassostrea gigas* from a disused oyster farm at Tighavullin, Scotland, were observed in 1993, nine years after the farm was shut down, though no young were observed (Smith 1994).

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Acknowledgements (contributions from questionnaire)

Dr S.D. Utting, Ministry of Agriculture, Fisheries and Food, Conwy.

Tiostrea lutaria

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Ostreoida
Species name:	*Tiostrea lutaria* (Hutton 1873)
Synonyms:	*Ostrea lutaria* Hutton 1873
Common name:	New Zealand flat oyster

Date of introduction and origin

Tiostrea lutaria was first introduced to Britain from New Zealand to the MAFF Fisheries Laboratory, Conwy, north Wales, for quarantine procedures. Individuals were introduced into the wild in 1963 but these died out in the severe winter. A subsequent introduction was made in 1970 into the Menai Strait from seed produced at Conwy in 1966 (Walne 1979; Utting 1987).

Method of introduction

Deliberate commercial introduction of brood stock oysters was made into quarantine.

Reasons for success

Unknown.

Rate of spread and methods involved

This species has spread less than 1 km in 25 years. This oyster broods its larvae to the stage of metamorphosis so that upon liberation from the parent, the larvae settle within a few hours in the vicinity of the parent.

Distribution

It is found in the Menai Strait, North Wales.

Factors likely to influence spread and distribution

This species cannot survive severely cold winters (Utting & Spencer 1992) and can be preyed upon where no alternative prey items are present (Richardson *et al.* 1993).

Effects on the environment

Unknown.

Effects on commercial interests

It is a commercially important edible species.

Control methods used and effectiveness

None used.

Beneficial effects

It is of potential commercial importance but is susceptible to the disease of flat oysters caused by *Bonamia* sp. so it is not viable to cultivate them commercially in the UK (S.D. Utting pers. comm.).

Comments

Tiostrea lutaria is thought to be conspecific with the Chilean oyster *Tiostrea chilensis* with the latter name possibly taking priority (Buroker *et al.* 1983).

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Acknowledgements (contributions from questionnaire)

Dr S.D. Utting, MAFF Fisheries Laboratory, Conwy.

Ensis americanus

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Veneroida
Species name:	*Ensis americanus* (Gould in Binney 1870), following the taxonomy of van Urk (See 1964 & 1972 references in Urk (1987)).
Synonyms:	*Ensis directus* auctt. non *Solen directus* (Conrad 1843)
Common name:	American jack knife clam

Date of introduction and origin

Ensis americanus was found in 1989 on Holme beach, Norfolk (Howlett 1990). It is native to the Atlantic coast of North America and is thought to have been introduced from there, probably via mainland Europe (K. Essink pers. comm.).

Method of introduction

It was supposedly introduced to Europe as larvae in tanker ballast water; its spread within European waters has been by pelagic larvae (Cosel, Dörjes & Mühlenhardt-Siegel 1982).

Reasons for success

Unknown.

Rate of spread and methods involved

It has spread rapdily in southern North Sea countries (Essink 1985). *Ensis americanus* spread from its point of introduction in the German Bight in 1978 (Cosel, Dörjes & Mühlenhardt-Siegel 1982) around the North Sea coast of Denmark and The Netherlands (Essink 1985) by 1982, to Belgium by 1984 (Essink 1986) and France by 1986. It had reached the English

Channel by the end of the 1980s (see Luczak, Dewarumez & Essink (1993) for map). The pelagic larval stage is assumed to be transported with water currents (Cosel, Dörjes & Mühlenhardt-Siegel 1982).

Distribution

Currently it is found at sites along the British east coast south from the Humber and along the English Channel west as far as Rye Harbour, East Sussex. (Howlett 1990; J. Light & I. Killeen pers. comm.). It is common in the Wash (R. Bamber pers. comm.). Elsewhere in Europe it is found in the Low Countries (Boer 1984 and see above).

Factors likely to influence spread and distribution

It has long-lasting pelagic larvae.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

It is fished in some parts of continental Europe.

Comments

In some places, e.g. Southend on Sea, Essex, in 1995 it was reported to be one of the commonest living bivalves on the shore (J. Light & I. Killeen pers. comm.).

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Acknowledgements:

Dr K. Essink, National Institute for Coastal and Marine Management, The Netherlands.

Mercenaria mercenaria

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Veneroida
Species:	*Mercenaria mercenaria* (Linnaeus 1758)
Synonyms:	*Venus mercenaria* L.
Common name:	American hard-shelled clam, little-neck clam, quahog, cherry stone clam.

Date of introduction and origin

Mercenaria mercenaria originates from the east-coast of N. America (Nova Scotia, Canada to Yucatan, Mexico. The first live specimen was found in the Humber in 1864 and last recorded from Cleethorpes in 1907 (Heppell 1961). It was successfully introduced from the USA, possibly the New York area, in 1925 to Southampton Water (Mitchell 1974). There were earlier introductions but none resulted in the establishment of self-sustaining populations.

Method of introduction

There was deliberate commercial introduction a barrel of live clams was imported from the USA to be tried as eel bait. Some were laid in the River Test arm of Southampton Water in the cooling water discharge from the former town power station (Mitchell 1974). The point of introduction is now under the Eastern Docks extension. Some were introduced into the Fleet, Dorset, in the early to mid-1960s, where they persisted for some time but do not appear to have bred (D.R. Seaward pers. comm.). It is considered that some clams may also have been thrown overboard into Southampton Water from transatlantic liners using the port, but there is no direct evidence for this unlikely event (Ansell 1963).

Reasons for success

The population has apparently increased since the 1950s, possibly due to occupying the niche of the soft-shelled clam *Mya arenaria*, which was eliminated from the estuary by the cold winters of 1947 and 1962/63 (Mitchell 1974). The *Mya arenaria* population has never recovered. Favourable physical conditions are likely to be the prime reason for the original colonisation. There were ideal estuarine conditions available i.e. lowered salinity and soft substrata with temperatures elevated by power station cooling water discharges from Southampton power station and later Marchwood Power Station (opened in 1957) almost opposite the original site of introduction. Further heating of Southampton Water and the eastern Solent has occurred through industrial cooling water discharges from ESSO Fawley and the Fawley Power Station (Mitchell 1974, 1976). Furthermore, it appears that this species has become physiologically adapted to be able to spawn at 3-4°C lower (i.e. 18-19°C) than populations in its area of origin (Mitchell 1974, 1976). Hibbert (1976) recorded some spawning at 17°C.

Rate of spread and methods involved

Since the original introduction to upper Southampton Water in 1925, the population has spread naturally by larval dispersal along the eastern side of Southampton Water and into Portsmouth and Langstone Harbours in The Solent. Some dumping from the fishery has probably helped to augment the populations in Portsmouth and Langstone Harbours. A substantial number have also been introduced to Newtown Harbour, Isle of Wight, and the Blackwater Estuary, Essex. Specimens obtained from the north Isle of Wight are never smaller than 80 mm suggesting that this population is not breeding (J. Light & I. Killeen pers. comm.).

Distribution

The extent of its current occurrence is the eastern side of Southampton Water, Portsmouth and Langstone Harbours, sporadically between Newtown Harbour and Ryde Pier along the north coast of the Isle of Wight (J. Light & I. Killeen pers. comm.) and the Blackwater Estuary, Essex. In Europe populations exist in The Netherlands and France but it is not known whether these are self-sustaining.

Factors likely to influence spread and distribution

Elevated estuarine temperatures through heated industrial discharges are likely to favour the spread of this species in British waters, especially where the temperature required for reproduction is reached. Dumping and deliberate introduction attempts by fishermen and fishery scientists also influence its spread.

Effects on the environment

It filled the niche left by the cold weather die-off of the soft-shelled clam *Mya* and thus prevented they re-establishment of *Mya*. Digging and dredging for this clam has a significant effect on the environment, particularly eel grass *Zostera* beds (Cox 1991; Anon. 1992). The populations of *Mercenaria* in the Solent are now very low (MAFF pers. comm.).

Effects on commercial interests

No commercial interest is known to have been adversely affected by the arrival of this species. Instead it has supported a thriving fishery from the 1960s to the present. Latterly the fishery has been severely depleted, primarily due to poor spatfall (MAFF pers. comm.), but possibly due also to the large numbers taken and physical damage to the environment.

Control methods used and effectiveness

The species is not controlled although the population has been severely depleted by the fishery.

Beneficial effects

See above.

Comments

The history of *Mercenaria mercenaria* in England has shown that deliberate introductions can work commercially.

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Petricola pholadiformis

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Veneroida
Species name:	*Petricola pholadiformis* Lamarck 1818
Synonym:	*Petricolaria pholadiformis*
Common name:	False angel wing, American piddock

Date of introduction and origin

Petricola pholadiformis was introduced not later than 1890 (Naylor 1957) and found in the River Crouch, Essex (International Council for the Exploration of the Sea; 1972, Tebble 1976). The species is native to the USA and was introduced from there.

Method of introduction

It was an associated unintentional introduction with the American oyster *Crassostrea virginica* (Rosenthal 1980**).**

Reasons for success

Unknown.

Rate of spread and methods involved

Rosenthal (1980) indicates that this species has colonised several northern European countries by means of it pelagic larvae. It also possibly spread in drift wood.

Distribution

It is established along south and east coasts of England from Lyme Regis, Dorset, to the Humber, Humberside (Duval 1963; J. Light & I. Killeen pers. comm.), where it is found living in clay, peat or soft rock shores. It is most common off Essex and the Thames estuary e.g. the River Medway (see Bamber 1985). European populations occur from southern Norway to the Mediterranean and Black Seas (Tebble 1976).

Factors likely to influence spread and distribution

Its spread is influenced by ocean currents as it disperses through larval transport.

Effects on the environment

In Belgium and The Netherlands it has almost completely replaced the native species *Barnea candida* (International Council for the Exploration of the Sea; 1972). In Britain, however, there is no documentary evidence for its having displaced native piddocks (J. Light & I. Killeen pers. comm.).

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

None known.

Comments

Petricola is remarkably similar to *Barnea candida* (an indigenous British species).

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Mya arenaria

Phylum:	Mollusca
Class:	Pelecypoda
Order:	Myoida
Species name:	*Mya arenaria* (Linnaeus 1758)
Synonyms:	None
Common name:	Soft-shelled clam, soft clam, long-necked clam.

Date of introduction and origin

Mya arenaria is thought to have been introduced from the American coast during the 16th or 17th century. However, there is also evidence that the Vikings transported this species to Europe from America as early as 1245 (Petersen *et al*. 1992).

Method of introduction

It may have been deliberately introduced for food or bait, or larvae may have been transported accidentally in the bilges of ships.

Reasons for success

Unknown.

Rate of spread and methods involved

This species has spread all around the coast of Britain, apparently by natural dispersal of larvae.

Distribution

It is found on all British and Irish coasts, and on European North Sea coasts from northern Scandinavia and the Faeroes to Arcachon in France (Seaward 1990).

Factors likely to influence spread and distribution

Unknown.

Effects on the environment

Unknown.

Effects on commercial interests

Unknown.

Control methods used and effectiveness

None used.

Beneficial effects

In the USA this species is considered a delicacy and is used for "clam-bakes" at the beach. However, in Britain its use as a food is uncommon.

Lessons to be learnt, Comments

Fossils of *M. arenaria* dating from up to the end of the Pleiocene Epoch which ended 1.6 million years ago show it was previously native to Europe. It is thought to have become extinct during the Pleistocene Epoch, when Europe passed through a series of ice ages (Foster 1946). It was introduced either by the Vikings or during the 16th or 17th century and has become re-established.

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Chordata

Styela clava

Phylum:	Chordata
Class:	Ascidiacea
Order:	Pleurogona
Species name:	*Styela clava* Herdman 1882
Synonym:	*Styela mammiculata* Carlisle 1954
Common name:	Leathery sea squirt

Date of introduction and origin

Styela clava was probably introduced in 1952, as it was found in Plymouth, Devon, in 1953 (Carlisle 1954; Houghton & Millar 1960). This species was introduced from the north-western Pacific, where it occurs from Japan to Siberia (Millar 1960).

Method of introduction

It was transported on the hulls of warships following the end of the Korean War in 1951.

Reasons for success

It is a hardy species, capable of withstanding salinity changes and temperature fluctuations.

Rate of spread and methods involved

Its spread has been rapid: from Plymouth in 1953 to Southampton Water in 1959 and Milford Haven in south-west Wales (Coughlan 1969) and across the Channel to France by 1968. It was first recorded in Ireland in 1972 (Minchin & Duggan 1988). Possible methods of dispersal include transport on ships' hulls or on transferred oysters.

Distribution

It is distributed on south and west coasts of England as far north as Cumbria. It is found in abundance in certain parts of the Solent (S. King pers. comm.), and also in certain parts of Loch Ryan and other scattered Scottish localities (S.M. Smith pers. comm.). Elsewhere in Europe it is found in France, The Netherlands, Denmark and Ireland (Minchin & Duggan 1988).

Factors likely to influence spread and distribution

It is believed only to be able to spawn in waters above 15°C.

Effects on the environment

Serious competition for food between individuals and with other species can result if the population becomes big enough.

Effects on commercial interests

It is a fouling pest on ships' hulls and oyster beds.

Control methods used and effectiveness

Biological control through the deliberate introduction of *Carcinus maenas* into cages surrounding the sea squirt has proved to be an unsuccessful control agent. Various combinations of salinity, temperature and exposure to air have proved successful in killing *Styela clava* without causing the host oysters any mortality.

Beneficial effects

None are known, though it harbours many epibionts so may aid localised increases in biodiversity.

Comments

In Lancashire this species was first found in a man-made pool at Morecambe from where it spread to other high-level pools, under boulders and stones and down the shore (Coughlan 1985).

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