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Non-natives

CHRISTINE MAGGS[1], FRÉDÉRIC MINEUR[1], JOHN BISHOP[2], AND TRACY MCCOLLIN[3]

[1]School of Biological Sciences, Queen's University Belfast, Belfast BT9 7BL

[2]Marine Biological Association, Citadel Hill, Plymouth PL1 2PB

[3]Marine Scotland – Science, Marine Laboratory, PO Box 101, 375 Victoria Road, Aberdeen, AB11 9DB

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EXECUTIVE SUMMARY

- Climate change can affect every stage of the introduction, colonization, establishment and invasion of alien species; this report examines the evidence for marine species in the UK and Ireland.
- The introduced Pacific oyster (*Crassostrea gigas*) spread from oyster farms in the early 1990s, becoming established in southern England. Similarly, new self-sustaining populations are now established in Northern Ireland with recruitment occurring in favourable years. Current sea temperature projections are thought likely to result in certain species such as *Crassostrea gigas* recruiting every year in Northern Ireland, Wales and south-west England by 2040.
- Rising water temperatures may have contributed to the expansion in range of a number of species such as the bryozoan *Bugula neritina*, previously restricted to warm water areas such as power station outlets, and the red seaweed *Caulacanthus ustulatus* which was introduced from Asia and spread rapidly to Devon in 2004, Cornwall in 2005 and Kent in 2009.
- The invasive gastropod, the slipper limpet *Crepidula fornicata*, which can build up enormous populations in southern England, seems to be expanding in range, possibly in association with rising temperatures, although its spread may be more related to aquaculture activities.
- Recent outbreaks of a viral disease of *Crassostrea gigas* oysters may be associated with climate change, and transport of oysters from France is spreading the virus.
- Changes in ocean physics and chemistry could favour some non-native species over native species.

FULL REVIEW

Introduction

Organisms introduced intentionally or unintentionally outside their native ranges are known as alien or non-indigenous species (NIS; Shine *et al.,* 2000). Those aliens that become established into existing ecosystems and subsequently threaten biodiversity and/or result in economic damage are referred to as invasive species (Shine *et al.,* 2000). To differentiate invasive aliens from invasive native species, for legislative and other purposes, they are often termed IAS (invasive alien species) or NNIS (non-native invasive species; see www.nonnativespecies.org). In general, more non-native species are arriving in marine habitats than ever before and some species are becoming more abundant; there is good evidence that some are causing major ecological changes on both local and global scales (Ruiz *et al*., 1997; 2000). Coastal marine ecosystems are potentially in a high-risk category, as globalization means there are now few barriers to the spread of invasive species. A cascade of physical and chemical changes in marine systems resulting from climate change (Harley *et al*., 2006) is thought likely to favour some non-native species relative to native species (Occhipinti-Ambrogi, 2007).

1. What is already happening?

There is increasing evidence, mostly from terrestrial systems, that climate change has enabled alien species to expand into new regions (Figure 1; Walther *et al*., 2009). Climate change can affect every stage of the introduction, colonization, establishment and invasion of alien species (Walther *et al*., 2009). Here we will look at each of these stages and examine evidence that climate change has affected the processes involved for marine species in the UK and Ireland.

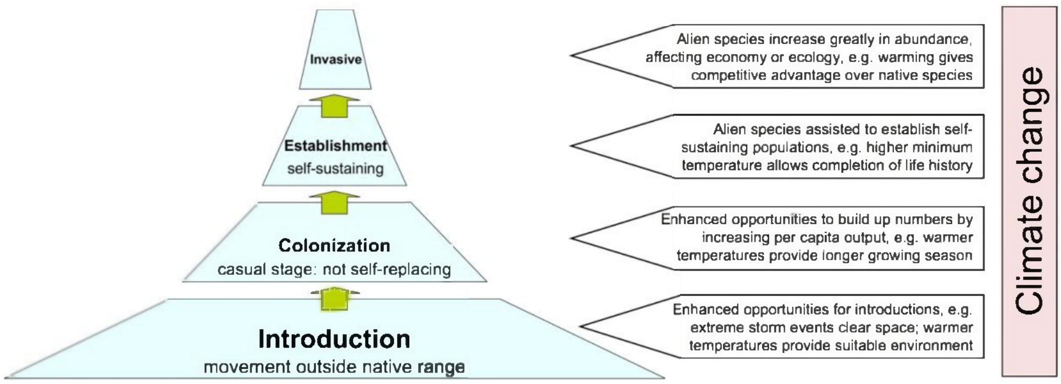


Figure 1. *Stages in the sequential transitions of a successful invasion process, modified from Walther et al.'s (2009) figure 1 and associated text.*

Stage 1. Introduction

Introduction is defined as direct or indirect movement by human agency of an organism outside its native range. Temperature is a key determinant of the natural distributions of marine organisms (Lüning, 1990). In temperate regions, introductions of a few individuals from warmer geographical regions can temporarily survive during short warm periods or in restricted favourable habitats. The presence of 'islands' of water with elevated temperatures, such as thermal effluents, can allow these species to survive introduction to the new geographical range in the short or medium term (Walther *et al*., 2009). However, such populations will not be self-sustaining unless thermal adaptation occurs.

In the UK, an example of a species with this type of distribution is the bryozoan *Bugula neritina,* well-known for producing bryostatin, with anti-cancer effects (Davidson & Haygood, 1999). *B. neritina* had been introduced from warm temperate or tropical regions to southern Britain early in the 20th century (Ryland, 1960). It was apparently confined to the vicinity of power station cooling water discharges, but may have been eliminated by the cold winter of 1963 (Ryland *et al*., in press; Eno *et al.,* 1997) regarded it as “no longer established [in Britain] in the wild”. Over the last 5-10 years, it has become widespread on the south coast of England (Regions 3 and 4) (Arenas *et al*., 2006a), and is now present on the east coast of Ireland (Ryland *et al*., in press) and the southern North Sea (Region 2) as far north as Lowestoft (Ryland *et al*., in press). This reappearance and spread may be a result of sea surface temperature (SST) increases of 1-1.5°C over the last 50 years, but it is also possible that a lineage with better tolerance of lower temperatures has been introduced, replacing the original strain. In a Plymouth marina (Region 4) with temperatures similar to those of the open sea, production of larvae by *B. neritina* was not restricted to the warmest season but occurred during at least six months of the year in 2008-9 (Glass, 2009). Because reproduction occurs for an extended period at Plymouth, this suggests that *B. neritina* could reproduce sexually further to the north.

Stages 2 and 3. Colonization and successful reproduction

Presence of an introduced species does not necessarily lead to successful establishment, due to the requirement to build up numbers to self-sustaining levels. Climatic conditions that favour sexual reproduction or increased per capita reproductive output can promote the transition to these stages, and may allow the non-native species to compete with native species.

Warming water temperatures have already allowed the farmed Pacific oyster, *Crassostrea gigas*, to establish self-sustaining populations on British coasts. *C. gigas* was deliberately introduced for commercial purposes after MAFF trials in the 1960s and early 1970s had indicated that the species required temperatures clearly in excess of those in British waters for successful reproduction in the wild (Mann, 1979; Utting & Spencer, 1992). Accordingly hatchery-produced seed were produced in large numbers for commercial rearing. However, natural recruitment has occurred increasingly within the British Isles, although with regional differences. Some local recruitment occurred in estuaries of south-west England and north Wales following unusually warm summers in 1989 and 1990 (Spencer *et al.,* 1994) and there are now well established adult populations around the south coast of England (Figure 2), especially in the south-east (Regions 2 and 3) where regular settlement of naturally produced spat occurs and is often used by growers as a source of seed for mariculture or as marketable oysters (Syvret *et al*., 2008). Fisheries are also sustained by natural spatfalls in the Netherlands and France.

Figure 2. *Pacific oysters (Crassostrea gigas) at Brightlingsea, Essex (Syvret et al., 2008)*

In Scotland it has been assumed that the low temperatures would mean that this species would be unable to establish itself. To date, there have been no substantiated records of spatfall in Scottish waters although maturation of the gonad and gamete release have been noted occasionally during atypically warm weather in south-west Scotland in shallow, sheltered sea lochs. However, over the past three years, spatfall has occurred at several locations in Strangford Lough, Northern Ireland (Guy & Roberts, 2010), so *C. gigas* has now become established there (Figure 3). In Strangford Lough, temperatures of over 18 °C were recorded occasionally in every year from 2004 to 2007, with a 20-day spell in 2006, when much of the recruitment occurred. A long term temperature data set from Millport on the Isle of Cumbrae in south-west Scotland indicates that maximum temperatures in this area are rarely above 16 °C.

Figure 3 *Crassostrea gigas at Strangford Lough, with section through mature gonads (section courtesy of Claire Guy, Queen's University Belfast).*

There is a wide variation in temperature profiles between regions. At present, low risk regions with respect to wild settlement of Pacific oysters include Scotland and north-east England; moderate risk regions include Northern Ireland, Wales and south-west England; high risk regions are southern England and south-east England (Syvret *et al.,* 2008). Current predictions for climate change imply that by 2040 regular recruitment will occur in the present 'moderate risk' regions that now only experience intermittent recruitment events (Syvret *et al.,* 2008). However, there is a lack of basic data with respect to actual seawater temperatures being experienced on shellfish culture sites. Acquiring this information would greatly increase the accuracy of the regional models.

A second oyster species, the New Zealand flat oyster (*Tiostrea lutaria*) has recently spread in the Menai Strait, North Wales (Region 5) in apparent response to warmer spring temperatures (Morgan, 2007); a small population has been present since deliberate release in the Strait in 1970, but had previously failed to spread (Richardson *et al.,* 1993).

The commercial species *Ruditapes philippinarum* (Manila clam) provides a further example of a bivalve assessed for aquaculture in Britain and considered to be unable to breed in the wild at the locally prevailing temperatures (Laing & Utting, 1994) that has nevertheless become naturalized and self-sustaining. The population in Poole Harbour (Dorset; Region 3) arising from a trial introduction in 1988 has supported a small commercial fishery since 1994 (Jensen *et al*., 2004), and the species is also abundant on intertidal mudflats of Southampton Water (Caldow *et al*., 2007) (also Region 3), and was recorded from the Stour/Orwell estuary (Suffolk; Region 2) by Ashelby *et al*., (2004).

Stage 4. Invasion

In the marine environment, the sudden northerly spread of established aliens can be linked to climate change, but there may be other factors involved, such as additional anthropogenic introductions. For example, the rapid northward expansion along the Atlantic coasts of France of the Mediterranean gastropod *Cyclope neritea* was primarily due to processes associated with aquaculture but it was also closely connected with increased seawater temperature in the Bay of Biscay (Simon-Bouhet *et al*., 2006).

In the UK, a few invasive marine species are thought to be limited in distribution by water temperature, although in general experimental evidence is lacking. In many cases, the site of the first UK introduction was southern England, often the Solent, so it is difficult to distinguish general range expansion from a point of initial entry from northwards spread. An example of an invasive species that may be expanding its range in association with increasing temperatures is the slipper limpet, *Crepidula fornicata*, which originated in the eastern USA. It has been present in Britain for over 120 years following accidental importation with Chesapeake Bay Oysters (*Crassostrea virginica*) yet until recently was confined to England, mostly the south and south-east coasts. It spread to France and has now reached enormous abundances there (e.g. 214 000 t in the Bay of Mont-St Michel) with major consequences for the natural benthic community and its component species (Goulletquer *et al*., 2002). In 2009 it was observed in Northern Ireland for the first time, probably associated with transfers of seed mussels to Belfast Lough, and shellfish movements have now been stopped. Whether this population will become self-sustaining is unknown. A recent study failed to document self-sustaining populations north of Milford Haven off the Welsh coast (also Region 5) (Bohn *et al*., 2009). Although the expanding range of occurrence of *C. fornicata* in Europe has been associated with higher minimum winter temperatures (Minchin *et al.,* 1995; Thieltges *et al*., 2004), the native distribution of *C. fornicata* includes the St Lawrence estuary, and it already occurs sparsely in southern Norway, so it is apparently tolerant of cold winters and high summer temperatures are possibly also a significant determinant of its range. In the Wadden Sea, brooding occurs in April-September and larvae are in the water from May-October, first appearing as the water temperature reaches 10°C (Thieltges *et al*., 2004). The critical factor may be whether populations are subtidal or intertidal, as intertidal populations show high mortality in cold winters (Thieltges *et al*., 2004) possibly explaining why the spread has been restricted to subtidal habitats.

The Asian strain of the red seaweed currently known as "*Caulacanthus ustulatus*" (taxonomic status under revision: F. Mineur *et al*., unpubl.) is an invasive alien species probably introduced into Europe from Japan with shellfish transfers. It was first found at Roscoff (France) in 1986 (Rio & Cabioc'h, 1988), where it had a restricted distribution. Now, however, the species has become invasive (Figure 5), being widely distributed in Europe, overlapping in the Mediterranean Sea and on southern Atlantic European coasts with a different, native species also known as *Caulacanthus ustulatus.* It has reached the Oosterschedt estuary (Netherlands) and in the UK, the species has spread rapidly to Devon (2004), Cornwall (2005) and Kent (2009) (Mineur *et al*., in prep.; Ian Tittley, pers. comm.). Unlike other exotic seaweeds that are predominantly found subtidally or in rockpools, "*C. ustulatus"* tends to invade the intertidal where it can become dominant and may exclude native macroalgal turfs. Its explosive spread may be linked to elevated SSTs in southern England.

Figure 4. *Invasive strain of the red alga Caulacanthus ustulatus (courtesy Auguste Le Roux).*

Global warming is often associated with the spread of alien pests and diseases, and it may be contributing to the recent outbreak of a viral disease of *Crassostrea gigas* oysters. In 2008, French stocks of *C. gigas* suffered high mortalities, and in summer 2009 this spread to stocks in Ireland. In Ireland, summer mortalities were only observed in sites where livestock had been imported from France (www.marine.ie/home/aboutus/newsroom/news/UpdateonOysterMortalities.htm). Recently it has been revealed that the cultivated oysters were affected by the Ostreid herpes virus 1 (OsHV-1) pathogen (Arzul *et al.,* 2001; Sauvage *et al*., 2009). This is the only known category of herpes virus to affect invertebrates (Davison *et al.,* 2005). Even if the origin of the virus involved in this episode remains unknown, it is likely it is an alien. Climate change Many marine organisms including exotic seaweeds hitch-hike along with shellfish transfers (Mineur *et al*., 2007). There is no doubt that many species originating from the continent are introduced (i.e. released into the wild) into British and Irish waters, and that these potentially include elements of the pool of exotic species already established in mainland Europe. It seems likely that global warming will increase the rate of successful establishment of such species in Britain and Ireland.

2. What could happen in the future?

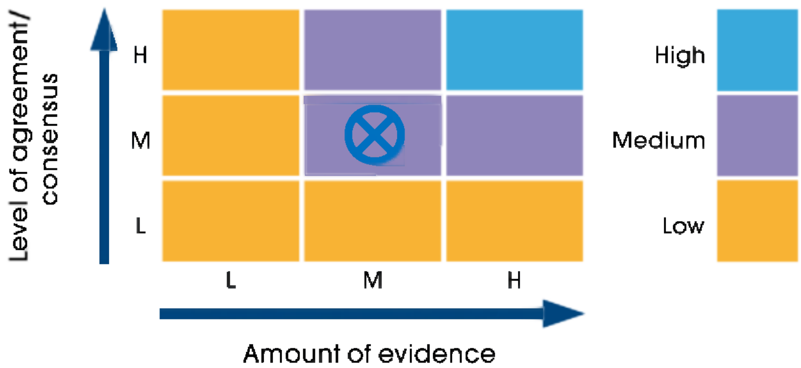
From the point of view of non-native marine organisms, the most significant changes in UKCP09 Climate Projections for 2070-98 are the 2-3°C increase in sea surface temperatures around much of Britain, and the increased storm surges. Temperature increases will affect all four stages of invasion outlined in Figure 1, and increased storminess will have particular effects on the introduction phase, opening up gaps in canopies of native species that could favour the establishment of invasive species such as Asian "*Caulacanthus ustulatus*".

Some definite predictions for particular species can be made on the basis of temperature projections, when there is sufficient biological information. The red seaweed *Bonnemaisonia hamifera*, native to Japan, has precise controls on its periodicity of spore formation, controlled by daylength and temperature. It sporulates in autumn, when the temperature is 13-19°C and the daylength is shorter than 12 h. In Japan, this fertile 'window' lasts for a longer period than in Britain, where the autumn sea surface temperature quickly drops below 13°C; in Norway, spore formation does not occur due to the cooler temperatures so *B. hamifera* reproduces only clonally (Lüning, 1990). An increase of 3°C in autumn temperature as predicted for southern Britain and Ireland by 2070-98 would lengthen its period of spore formation (meiosis) by a month or more. Meiosis would permit more genetic variation and could result in adaptive genotypes as has been proposed for *Undaria* (Voisin *et al.,* 2005), and potentially larger populations. As this species has been shown to have potent allelopathic effects on other algae due to its production of a poly-brominated 2-heptanone (Nylund *et al*., 2008), a loss of native algal diversity might ensue.

Some of the most damaging invasive marine species in Europe are currently restricted in their invasive distributions. For example, *Caulerpa racemosa* var. *cylindracea* is confined to the Mediterranean Sea and Canary Islands, but within the next century could also survive in southern England (Verlaque *et al*., 2004). Another example here could be the potentially toxic dinoflagellate *Gymnodinium catenatum*, which is currently restricted to warmer waters in the south of Europe but a combination of warmer waters and human mediated transport e.g. in ballast water, could allow this species to extend its range northward (Minchin & Eno, 2002).

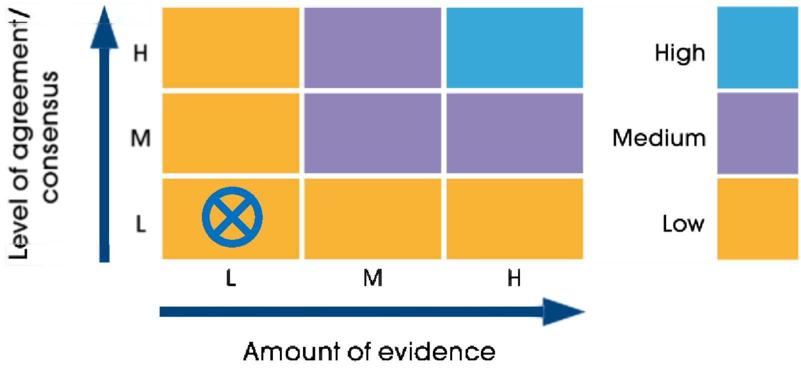
3. Confidence in the science

What is already happening: **Medium**



Climate driven changes may affect directly native species performance, modifying population dynamics which can ultimately result in distributional shifts and changes in the composition and diversity of coastal communities (e.g. Ling, 2008) as well as coastal habitat loss. Similarly, other global stressors like marine invasions have profound and often irreversible consequences on the ecology and economics of marine systems (Grosholz, 2002). Despite the mounting research effort dedicated to the study of climate change and IAS in the marine realm, empirical studies linking both these global stressors are limited and mostly observational (e.g. Harris & Tyrrell, 2001; Diederich *et al.*, 2005). Interactions between climate changes and biological invasions may have widespread and unexpected effects on coastal ecosystem dynamics (Harley *et al.*, 2006).

What could happen: **Low**



The level of confidence has been decreased since the 2007-08 MCCIP ARC. This may be because the previous report focused on the arrival and spread of new aliens rather than their biology and impacts, which are more poorly understood.

4. Knowledge gaps

The top priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

1. Relevant biological information on invasive species (e.g. molecular data indicating origins; population genetics; and physiological tolerances) is still lacking for the great majority of species, meaning that confident predictions of the future trajectory of existing invasions cannot be made for many aliens.
2. There is very little information on the ecological effects of alien species interacting with native species for all but a few species in a few locations (Arenas *et al.*, 2006b), so that even if we knew what the species would do, we would not be able to predict its effects on native species.
3. The lack of integration concerning knowledge gaps (1) and (2) means that potential effects of climate change on native species are still very poorly understood - results to date are often conflicting, counter-intuitive, and strongly confounded by other anthropogenic factors.

We believe there is a strong consensus about these knowledge gaps.

5. Socio-economic impacts

Oyster disease:

IFREMER is believed to be researching this outbreak. It has already had serious impacts on European oyster cultivation and these could become more widespread.

Crepidula

The spread of *Crepidula* to Northern Ireland has stopped *Mytilus* relaying and export www.bbc.co.uk/newsline/content/articles/2009/05/26/invasive_species_feature.shtml

Further spread will have effects on the aquaculture industry. Northern Ireland Environment Agency are commissioning research on this species.

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