IMPACTS OF CLIMATE CHANGE ON NON-NATIVE SPECIES

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Executive Summary

Non-indigenous species are becoming increasingly common in marine habitats, and are causing major ecological changes on both local and global scales (Ruiz *et al.*, 1997; 2000). Most species have reached new localities by anthropogenic dispersal such as deliberate introduction, fouling on the bottom of ships, or through the release of organisms in ballast water (Ruiz *et al*, 1997, Eno *et al.*, 1997). Many factors can then affect the successful establishment of the species, such as the presence of predators, availability of unfilled niches, and the presence of food (Eno *et al.*, 1997, Hawkins *et al.*, 2004). There is also a growing body of evidence that most aspects of global climate change favour the successful establishment of invasive alien species (Dukes & Mooney, 1999; Carlton, 2000; *Stachowicz et al.*, 2002).

Climate change has been proposed to affect marine invasions in a number of ways. Firstly, warm water-indigenous species may expand ranges to the warming higher latitudes and out-compete cold-adapted species through their greater growth and recruitment (Carlton, 2000; Stachowicz *et al.*, 2002). Secondly, climate change may alter primary trophodynamic regimes and oceanography, indirectly facilitating invasions (Carlton, 2000; Hulme, 2005). Thirdly, successful invaders tend to be more resilient to disturbances than native species, and thus climate change could combine with other stresses to allow invaders to out-compete native species (Rogers & McCarty, 2000).

Unfortunately, evidence and models of the effects of climate change on invasive spread are rare. However, many studies have revealed a correlation between water temperature and success of marine invaders. For instance, Stachowicz *et al*. (2002) found that three invasive species of ascidians in the USA can out-compete native species in warm years. Also, in the UK, many of our marine invasive species are thought to be limited in distribution by water temperature Examples include the tubeworm, *Ficopomatus enigmaticus* (Zibrowius & Thorp 1989), the barnacle *Elminius modestus* (Eno *et al.*, 1997), and the algae, *Codium Fragile* (Hardy 1981). It is likely that increasing water temperatures will further facilitate the spread of these species, and possibly allow introductions of new and notorious warm-water invaders such as the Northern Pacific Sea Star, *Asterias amurensis*, or the Caulerpa Seaweed, *Caulerpa Taxifola*.

Level of Confidence

Medium

Key sources of Information

See Supporting Evidence

Supporting Evidence

A review of the models that can be used to predict the spatial spread of new invasions is presented by Hastings *et al.* (2004), while a concise summary of the factors affecting marine invasions is summarized by Ruiz *et al.* (1997). Theoretical work has shown that invasive species' spread is a far more complex process than classical models have implied, because long-range dispersal can rapidly enhance range expansion. Many attempts to model the effects of climate change have often used "climate envelopes" to predict future changes in species distribution. Such models often predict that climate change may reduce the suitability of current habitat, and these threats are most likely to be felt by species of limited dispersal ability (Hulme, 2005), i.e. non-invasive species.

Empirical work emphasises the effects of spatial heterogeneity, temporal variability, other species, and evolution on invasions (Hawkins *et al.*, 2004). However, evidence remains scarce regarding the effects of directed environmental change on invasive spread. For many species, effects may be indirect and result from changes in the availability of natural resources and mutualistic and antagonistic interactions between species (Hulme 2005). The emergent patterns of marine invasion in North America reflect interactive effects of propagule supply, invasion resistance and sampling bias (Ruiz *et al.*, 2000).

Many invasive species can be expected to follow the same biogeographical range shifts in response to changing environmental conditions as other marine organisms (Harley *et al.*, 2006; Fields *et al.,* 1993; Keister *et al.*, 2005; Perry *et al.*, 2005; Southward *et al.,* 1995). However, temperature changes can also differentially affect the growth and reproduction of native and invasive species. For instance, Stachowicz *et al.* (2002) found for three introduced species of sea squirt at Avery point, Connecticut (USA), recruitment occurred earlier and with greater magnitude in years with warmer winters. In contrast, the timing of native recruitment was unaffected by temperature, and more recruitment happened in colder years. Further, in manipulative laboratory experiments, invasive ascidians grew faster than native species, but only at temperatures near the maximum temperatures observed in the summer. Together, these data indicate that global warming could speed and increase the recruitment and growth of invasive species, causing shifts in dominance relationships within communities.

Marine invasive species in the UK

A report by Eno *et al.* (1997) summarizes the distribution and invasive characteristics of 51 non-native species in British waters. These include 15 marine alga, 5 diatoms, 1 flowering plant and 30 invertebrates. There are generally no common patterns in the distribution of the invasive species, but there do seem to be more invasive species in the South and West Coasts of Britain, especially in the Solent (Zibrowius & Thorp, 1989) and along the Essex Coast (Utting & Spencer, 1992). Rates of spread vary between species, with 16 out of 51 species having spread to much of the British isles within 50 years. Most species originated from similar latitudes to the UK, especially the east coast of the USA (mainly fauna) and the Western Pacific (mainly flora). It is likely that most species made the journey to Britain via deliberate introduction (often in association with mariculture), or with transport on ships hulls, or in ballast water. The UK also often supplies Ireland with invasive marine species (Invaders of Ireland are summarized in: Minchin & Eno, 2002).

The most common individual reasons for the successful establishment of non-natives in British waters appear to be favourable physical factors, including a favourable temperature range (Eno *et al.*, 1997). Invasions are more likely if sea water temperatures are elevated in relation to regional or local conditions. Warm water species, which include most of the introduced shellfish, may only breed under conditions of high water temperatures. Other factors contributing to successful invasions included a lack of predators, availability of unfilled niches, presence of food and the general hardiness of the species, but it appears that climate change could certainly enhance the spread of many established invasive species.

Some examples of UK marine invasive species which could be affected by changing water temperatures are summarized below:

- *Hydroides dianthus* and *Hydroides ezoensis* are annelid tubeworms which were introduced into Southhampton water in the 1970s. *H. dianthus* does not appear to have the temperature restrictions of other species of the genus hydroides (Zibrowius and Thorp, 1989), while the success of *H.ozoensis* has been attributed to long hot summers, which contribute to high phytoplankton levels within the water (Eno *et al.*, 1997).

- *Ficopomatus enigmaticus,* is another annelid tubeworm 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). It can only survive in artificially heated Northern waters.

- The barnacle, *Elminius modestus*, can grow rapidly and withstand higher temperatures than native *Balanus* species and is now distributed all around the British mainland coast. Low water temperature is likely to restrict northwards spread of this species; *Elminius* increased considerably in abundance in the Clyde following the warm summer of 1959 (Barnes and Barnes, 1960).

- The slipper limpet, *Crepidula fornicata*, may spread if water temperatures rise; minimum winter temperatures may be important in limiting the development of large populations in the north of Britain (Minchin, McGrath & Duggan 1995).

- The Leathery sea squirt, *Styela clava* , has spread extremely rapidly in Britain. It is found on the South and West Coasts of England as far North as Cumbria, and it is believed to be limited by a spawning temperature minimum of 15°C (Eno *et al.*, 1997).

- The Jap weed, *Sargassum Muticum*, was first found in the English Channel in the late 1960s (Farnham, 1981) and spread rapidly along entire Channel coast (Hiscock & Moore 1986) and East coast up to Suffolk. Ideal conditions for growth are 25°C, but the species will grow at temperatures from 10°C to 30°C. Increasing temperatures could facilitate its spread Northwards.

- *Bonnemaisonia hamifera* and *Asparagopsis armata* are red algae that likely to be limited in distribution by water temperature (Eno *et al.*, 1997). Other Rodophyta species such as *Antithamnionella ternifolia* and *Polysiphonia harveyi* are very tolerant of temperature changes, and may out-compete native species.

- *Codium Fragile*, or green sea fingers, may be limited by limited by cool summer temperatures, particularly on the east coast (Hardy, 1981).

- It is also worth noting that many estuarine species have been spreading rapidly through Britain, such as the Chinese Mitten Crab, *Eriocheir sinensis* (Herberg *et al.*, 2005), the zebra mussel, *Dreissena polymorpha* (Aldridge *et al.*, 2004) and the Asian clam, *Corbicula Fluminae* (pers.obs). There is certainly some evidence that zebra mussel larvae are developing more rapidly than historically documented, which could be related to climate change (Elliott, 2005).

The most recent invasive species in the UK include the polychaete *Marenzellaria viridis* and the oriental shrimp *Palaemon macrodactylus* (Mark Davison, Thames Environment agency, *pers.comm.*) Future invasions of Britain could include the shellfish-poisoning dinoflagellate *Gymnodinium catenatum*, and the brown alga *Undaria pinnatifada* (Minchin & Eno, 2002).
With sufficient water warming, it is even possible that some of the more notorious global warm-water invasive species may enter British waters, such as the Northern Pacific Sea Star (*Asterias amurensis*), Caulerpa Seaweed (*Caulerpa Taxifola*), and the American Comb Jelly (*Mnemiopsis leidy*i). It is clear that detailed risk assessments and contingency plans need to be urgently prepared for future invaders and that these must be informed by detailed monitoring of the effects of climate change on the dispersal and growth of established invaders. Further, the question of how climate change will interact with other ecological pressures (such as invasive species or habitat fragmentation) to create synergistic effects also needs to be considered (Sutherland *et al.*, 2006).

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References

Aldridge, D.C., Elliott, P. & Moggridge, G.D. (2004). The recent and rapid spread of the zebra mussel (*Dreissena polymorpha*) in Great Britain. *Biological conservation*, **119**, 253-261.

Barnes, H., & Barnes, M. (1960). Recent spread and present distribution of the barnacle Elminius modestus Darwin in north-west Europe. Proceedings of the Zoological Society of London, 135: 137-145.

Carlton, J.T. (2000). Global change and biological invasions in the oceans. In: Invasive species in a changing world eds. Mooney, H.A. and Hobbs, R.J.. Island press, Covelo, CA. pp 31-53.

Chapman, J.W. (2000). Marine bioinvasions: Proceedings of the First National. Conference, 66-80.

Crisp, D.J. (1958). The spread of *Elminius modestus* in north-west Europe. *Journal of the Marine Biological Association of the United Kingdom*, **37**: 483-520.

Dukes, J.S. and Mooney, H.A. (1999). Does global change increase the success of biological invaders. *Trends in Ecology and Evolution*, **14** (4),135 – 139.

Elliott, P (2005). The zebra mussel in England: biology, effects and control using micro-encapsulated toxins. PhD thesis, Department of Zoology, University of Cambridge, Cambridge, UK. Chapter 5, 99-130.

Eno, C.N., Clark, R.A., Sanderson, W.G. (1997). Non-native marine species in British waters: a review and directory. Joint Nature Conservation Committee, JNCC Peterborough.

Farnham, W., Murfin, C., Critchley, A., & Morrell, S. (1981). Distribution and control of the brown alga *Sargassum muticum.* In: Proceedings of the Xth International Seaweed Symposium, 277-282.

Fields, P.A., Graham, J.B., Rosenblatt, R.H & Somero, G.N. (1993). Effects of expected global climate change on marine faunas. *Trends in Ecology and Evolution*, **8**, 361 -367.

Harley, C.D.G., Hughes, A.R., Hultgren., K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, L., Williams, L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters*, **9**, 228-241.

Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., Ostfeld, R.S. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science*, **296**, 2158-2162.

Hastings, A., Cuddington, K., Davies, K.F., Dugaw, C. J., Elmendorf, S., Freestone, A., Harrison, S., Holland, M., Lambrinos, J., Malvadkar, U., Melbourne, B.A., Moore, K., Taylor, C., Thomson, D.(2005). The spatial spread of invasions: new developments in theory and evidence. *Ecology Letters*, **8**(1) 91-101.

Hawkins, S.J., Southward, A.J., Genner, M.J. (2003). Detection of environmental change in a marine ecosystem –evidence from the western English Channel. *The Science of the Total Environment* **310**, 245-256.

Herborg, L.M., Rushton, S.P., Clare, A.S., Bentley, M.G.(2005). The Invasion of the Chinese Mitten Crab (*Eriocheir sinensis*) in the United Kingdom and Its Comparison to Continental Europe. *Biological invasions*, **7**(6), 959-968.

Hiscock, K., & Moore, J. (1986). Surveys of harbours, rias and estuaries in southern Britain: Plymouth area including the Yealm. Nature Conservancy Council, CSD Report, No. 752.

Hulme, P.E. (2005). Adapting to climate change: is there scope for ecological management in the face of a global threat? *Journal of Applied Ecology*, **42** (5), p784.

ICES (2005a). Working Group on Introductions and Transfers of Marine Organisms Documents annually from national reports the spread and impact of invasive spp. Available at http://www.ices.dk/iceswork/wgdetailacme.asp?wg=WGITMO. Last accessed 8 September 2006.

ICES (2005b). ICES/IOC/IMO Working Group on Ballast and Other Ship Vectors. Available at http://www.ices.dk/iceswork/wgdetailacme.asp?wg=WGBOSV. Last accessed 31 August 2006.

IPCC (2001). Climate Change 2001, synthesis report. A contribution of working groups, I, II, and III to the third assessment report of the intragovernmental panel on climate change. Cambridge University press, Cambridge, UK.

Eno, N.C., Clark, R.A. & Sanderson, W.G. (1997). JNCC report: Non-native marine species in British waters@ a review and directory. 1997. Available at http://www.jncc.gov.uk/pdf/pub02_nonnativereviewdirectory.pdf. Last accessed 31 August 2006.

Keister, J.E., Johnson, T.B., Morgan, C.A. & Peterson, W.T. (2005). Biological indicators of the timing and direction of warm water advection during the 1997/1998 El Niňo off the central Oregon coast, U.S.A/ Mar. *Ecological Progress Series* **295**, 43-48.

Minchin, D., & Eno, C (2002). Exotics of coastal and inland waters of Ireland and Britain. In: Invasive Aquatic Species of Europe: distribution, impacts and management. Leppakoski, E., Gollasch, S and Olenin, S. 206-216. Kluwer Academic Publishers, Dordreicht, The Netherlands.

Minchin, D., McGrath, D., & Duggan, C.B. (1995). The slipper limpet, *Crepidula fornicata* (L.), in Irish waters, with a review of its occurrence in the north-eastern Atlantic. *Journal of Conchology*, **35**, 247-254.

Mitchell, R. (1974). Aspects of the ecology of the lamellibranch *Mercenaria mercenaria* (L.) in British waters. *Hydrobiolgical Bulletin*, **8**, 124-138.

Miura, T., & Kajihara, T. (1984). An ecological study of the life histories of two Japanese serpulid worms, *Hydroides ezoensis* and *Pomatoleios kraussi*. In: Proceedings of the First International Polychaete Conference, Sydney, Australia July 1983, ed. by P.A. Hutchings: 338-354. The Linnaean Society of New South Wales.

Perry, A.L., Low, P.J., Ellis, J.R. & Reynolds, J.D. (2005) Climate Change and Distribution Shifts in Marine Fishes. *Science*, **5730**, 1912 – 1915.

Rogers, C.E. and McCarty, J.P (2000). Climate change and ecosystems of the Mid-Atlantic region. *Climate Research* **14**, 235- 244.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D., Hines, A.H. (1997). Global invasions of marine and estuarine habitats by Non-indeigenous species: mechanisms, extent and consequences. *American Zoologist*, **37**, 621-632.

Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M.J. & Hines, A.H. (2000). Invasion of the coastal marine communities of North America: Apparent Patterns, Processes, and Biases. *Annual Review of Ecology and Systematics*, **31**: 481-531.

Southward, A.J., Hawkins, S.J., & Burrows, M.T. (1995). Seventy years' observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. *Journal of Thermal Biology*, **20** (1-2), 127-155.

Stachowicz J.J., Terwin J.R,, Whitlatch R.B. & Osman RW. (2002). Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. *Proceeding of the National Academy of Sciences U S A*. **99**(24):15497-500.

Sutherland, W.J., Armstrong-brown, S., Armsworth, P.R., Brereton, T., Brickland., J., Campbell, C.D., Chamberlain, D.E., Cooke, A.I., Dulvy, N.K., Dusic, N.R., Fitton, M., Freckleton, R.P., Godfray, C.J., Grout, N.B., Harvey, J., Hedley, C., Hopkins, J.J., Kift, N.B., Kirby, J., Kunin, W.E., Macdonald, D.W., Marker, B., naura, M., Neale, A,R., Oliver, T., Osborn, D., Pillin, A.S., Shardlow, M.E., Showler, D.A., Smith, P.L., Smithers, R.J., Soland, J., Spencer, J., Spray, C.J., Thomas, C.D., Thompson, J., Webb, S.E., Yalden, D.W. & Watkinson, A.R. (2006). The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology*, **43** (4), Page 617.

Svensson, C.J., Jenkins, S.R., Hawkins, S.J. & Åberg, P. (2005). Population resistance to climate change: modelling the effects of low recruitment in open populations. *Oecologia*,**142**, 117 – 126.

Thorp, C.H. (1991). The effect of temperature on brooding in *Pileolaria berkeleyana* (Rioja, 1942) (Polychaeta: Spirorbidae). *Ophelia*, **5**, Supplement: 383-390.

Thorp, C.H. (1994). Population variation in *Ficopomatus enigmaticus* (Fauvel) (Polychaeta: Serpulidae) in a brackish water millpond at Emsworth, West Sussex, UK. *Memoires de Museum National d'Histoire Naturelle*, **162**: 585-591.

Utting, S.D., & Spencer, B.E. (1992). Introductions of marine bivalve molluscs into the United Kingdom for commercial culture - case histories. ICES Marine Science Symposium, 194: 84-91 Williamson, M. 1996. Biological invasions (Chapman and Hall, London).

Invasive non-native species in the UK (undated). University of Liverpool . Available at http://138.253.199.114/IAAP%20Web/IAAPwebsite/index.asp. Last accessed 31 August 2006.

Zibrowius, H., & Thorp C.H. (1989). A review of the alien serpulid and spirorbid polychaetes in the British Isles. *Cahiers de Biologie Marine*, **30**: 271-285.