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Conserving native biodiversity by raising awareness of invasive species

Final Report (2004 – 07)

Name of Organisation	<p>Scottish Association for Marine Science (SAMS)* Queens University Belfast (QUB) Marine Biological Association UK (MBA) University of Plymouth Natural History Museum (NHM) Marine Life Information Network (<i>MarLIN</i>)</p> <p>* Co-ordinating Organisation</p>
Grant reference number	EN / 04-0395
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Executive Summary

The intentional or accidental introduction of non-native “alien” species is second only to habitat destruction in causing the global loss of biodiversity. Alien species are also a serious impediment to conservation (Article 8; Convention on Biological Diversity). The UK Biodiversity Research Working Group recommended that research priorities focus on identifying the risks posed by alien species to UK biodiversity, including analysis of non-natives in relation to the Habitat and Species Action Plans specified in the UK Biodiversity Action Plan.

Prior to the Marine Aliens project, research in the UK on marine invasive species was highly disparate and localised. Over the last 3 years, this project has significantly raised the profile of non-native marine species in UK coastal waters and has been well received by government organisations and the general public alike. The team has concentrated on seven target non-native species, mapping their distribution, recording their spread and studying their biology, ecological impacts and their mechanisms of invasion.

Members of the Marine Aliens team have participated in 8 government-led working groups over the last 3 years, raising the profile of marine invasive species and directly influencing the development of the UK strategy for dealing with invasive non-native species.

The project has generated 19 peer-reviewed scientific papers in international journals and the data has been disseminated through a wide variety of scientific and popular media, including the popular website. In addition, it has resulted in 4 PhD studentships and 4 MSc/MRes theses. A number of international research collaborations (e.g. from USA, China, New Zealand, Australia, Germany, France, Norway, Germany, Ireland and the Netherlands) have also been established during the course of the project and resulted in a number of collaborative publications. These collaborations both increase the exchange of information and experience which can only be beneficial in the future production of action plans and raising public awareness for invasive species worldwide.

It is now critical that the momentum is continued and the results of this programme will be sent to the Convention of Biological Diversity and the GB Non-Native Species Secretariat to assist in the development of European and national action plans and conservation strategies.

1. **Please refer back to your application and summarise what we funded you to do.**

Project Objectives*:

- Production of a current UK distribution map
- Investigation of the impact on native biodiversity
- Determination of tolerance limits (e.g. temperature, salinity etc.) and prediction of potential spread throughout the UK
- Use of molecular genetic markers to identify origins, vectors of introduction, and dispersal rates
- Production of a case-study, as required by the EU Convention on Biological Diversity
- Development of an action plan and conservation strategy
- Publication of information via dedicated *MarLIN* web pages
- Increase public awareness and understanding of the issue with articles in appropriate magazines and the provision of publicity material at centres, such as ports/ harbours, marinas, the Natural History Museum and public aquaria

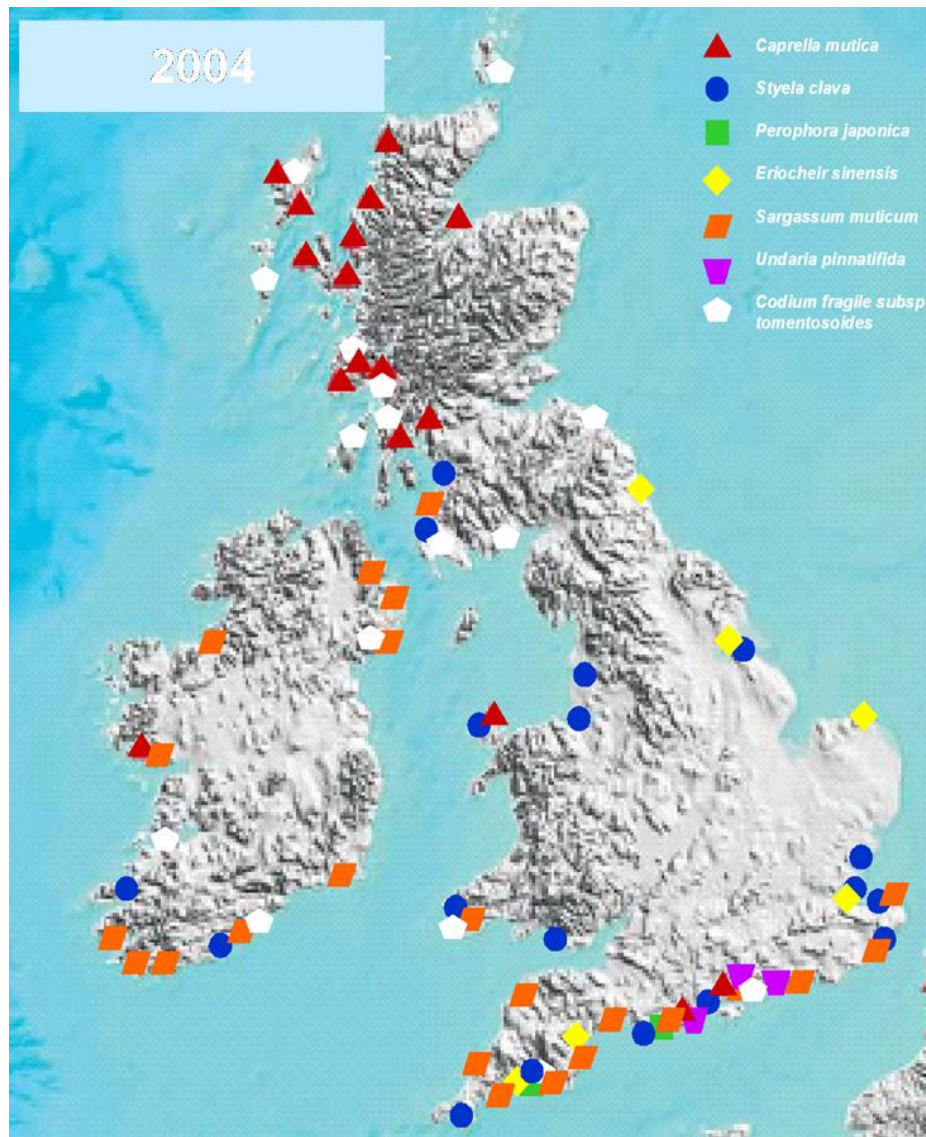
* Please note that not all these objectives were to be conducted for all of the seven marine non-native species – see individual workplans for details.

1. Have you achieved what you set out to do?

- **Production of a UK distribution map (Fig. 1)**

A distribution map for the seven non-native species in the UK has been produced and continuously updated throughout the project on the Marine Aliens website. This was the first map to be compiled for non-native marine species in the UK and from the collective knowledge of the Marine Alien partners, a total of 85 sites were plotted onto the map in 2004 (Fig. 1A). In the last 3 years, an additional 45 sites have been added to the map (Fig. 1B), particularly highlighting the northwards spread of *Sargassum muticum*; the presence of all seven species along the south coast of the UK; the extensive distribution of *Caprella mutica* and *Codium fragile* subsp *tomentosoides* throughout Ireland, Scotland and on the south and west coasts of England; the appearance of the mitten crab *Eriocheir sinensis* in apparently random ‘inland’ sites throughout England; and the relative paucity of the seven non-native species along the east coasts of England and Scotland.

A



B

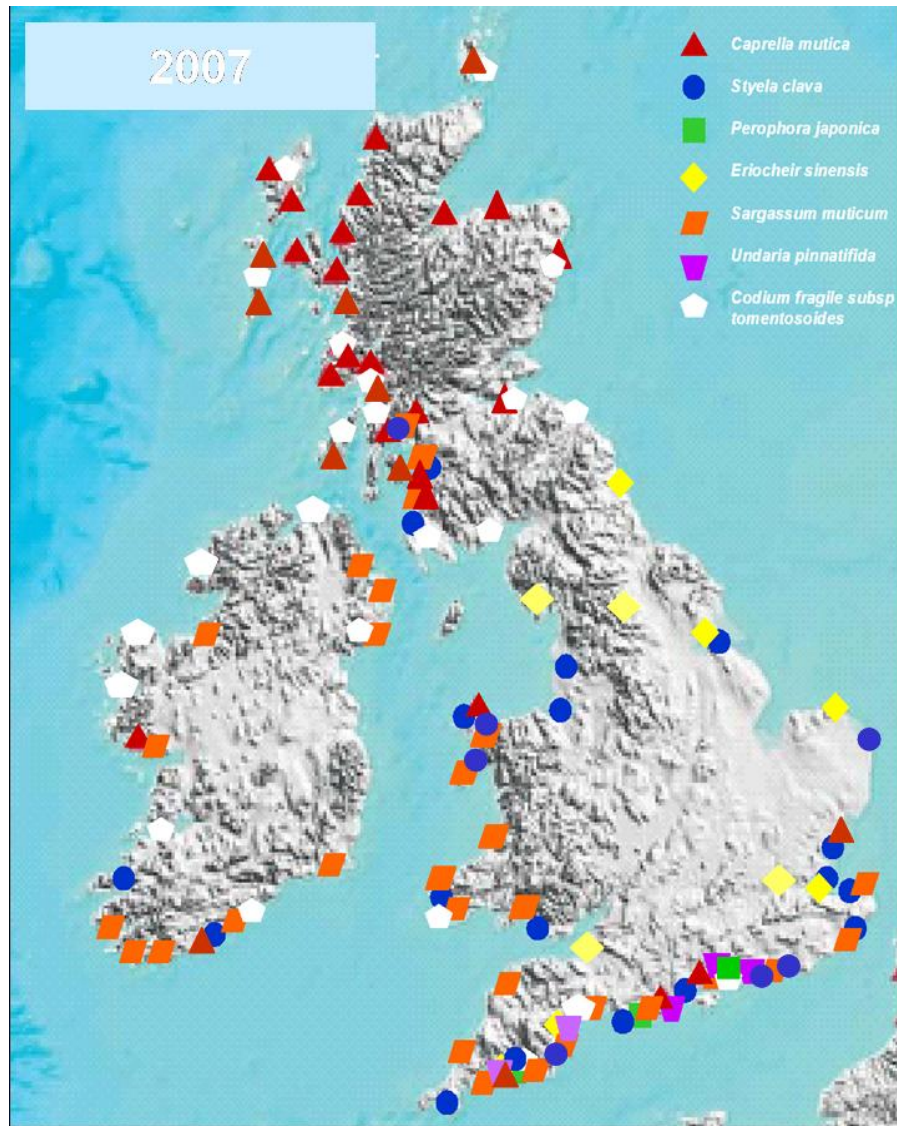


Figure 1. Distribution map for the seven non-native species featured in the Marine Aliens programme for (A) 2004 and (B) 2007

This paucity of species on the East coast of the UK, however, may be attributed to a lower sampling effort along this coast and this highlights the need for a concerted monitoring programme for non-native species throughout the UK.

Specific surveys of marinas on the south coast of England and around Scotland have been supported by this project and have greatly contributed to the data points shown on the distribution map (Fig.1 B).

In addition, the distribution data that has been generated through the Marine Aliens project has been sent to the co-ordinators of an EU project - Delivering Alien Invasive Inventories for Europe (DAISIE). This project is tasked with delivering an Alien Species Gateway to act as a “one-stop-shop” for information on biological invasions in Europe (www.daisie.se).

Papers:

Arenas, F., Bishop, J.D.D., Carlton, J.T., Dyrinda, P.J., Farnham, W.F., Gonzalez, D.J., Jacobs, M.W., Lambert, C., Lambert, G., Nielsen, S.E., Pederson, J.A., Porter, J.S., Ward, S., Wood, C.A. (2006). Alien species and other notable records from a rapid assessment survey

of marinas on the south coast of England. *Journal of the Marine Biological Association*. 86: 1329-1337.

Ashton, G.V., Boos, K., Shucksmith, R., Cook, E.J. (2006). Rapid assessment of the distribution of marine non-native species in marinas in Scotland. *Aquatic Invasions*. 4: 209-213.

Ashton, G.V., Boos, K., Shucksmith, R., Cook, E.J. (2006). Risk assessment of hull fouling as a vector for marine non-natives in Scotland. *Aquatic Invasions*. 4: 214-218.

- **Investigation of the impact on native biodiversity**

The impact of the non-native macroalgae, *Codium* and *Sargassum muticum*, the caprellid shrimp, *Caprella mutica* and the ascidian, *Styela clava* on native biodiversity has been investigated as part of the Marine Aliens programme.

- (i) *Codium*

Following the discovery in our herbarium sequencing study that *Codium fragile* subsp. *atlanticum* is a native endemic, we concentrated on comparisons of epiphytes between this and the invasive *tomentosoides* subspecies. Comparisons with *C. tomentosum* were also made, but are less useful as there are greater morphological differences between this and the invasive subspecies. The native subspecies appears to have a restricted distribution and may be becoming less common. We found it at only three sites on the north and north-west coasts of Ireland.

The two subspecies co-occurred in the same habitat only at Dooney Point, Donegal, where 3 subsp. *atlanticum* and 5 subsp. *tomentosoides* were collected. All epiphytic algae were removed, identified and enumerated. Despite the low replication, this analysis found significant evidence that the epiphytic assemblages on the two *Codium* basiphytes types were significantly different in composition. Over 40% of the dissimilarity observed between the epiphyte assemblages was generated by the substantial abundances of *Acrosiphonia* sp. and *Enteromorpha* spp. on *Codium fragile* subsp. *atlanticum*. By contrast, *Codium fragile* ssp. *tomentosoides* had an equally high abundance of *Cladophora* spp. There was no significant difference in total numbers of epiphytes, or any measure of diversity or richness.

Around the coasts of Ireland, subsp. *tomentosoides* supported epiphytes of another introduced seaweed, *Polysiphonia harveyi*, whereas this was not found on the native subspecies. In general, the replacement of subsp. *atlanticum* by subsp. *tomentosoides* would be expected to have an impact on a few epiphytic algae and enhance the abundance of *Polysiphonia harveyi*,

Irish populations of subsp. *tomentosoides* (49 individuals) were monitored by a novel beading technique during June and July 2006. Maximum length growth was 53 mm per month, as high as any rate previously recorded worldwide. Loss of thalli due to storms during this period was 50%.

Report: McLaughlin, M. Biodiversity of algal epiphytes on native and introduced species of *Codium* in Ireland. MSc thesis. Queen's University Belfast.

- (ii) *Sargassum*

Studies on *Sargassum* focused in two main areas, the impact of *Sargassum* on native intertidal communities in SW England and the role of local algal diversity in limiting invasion.

Manipulative work in intertidal rockpools demonstrated a relatively weak effect of *Sargassum* colonisation on native biota. Some reductions in the growth rate of sub-canopy species such as *Bifurcaria bifurcata* were seen, but general patterns of diversity were similar between impacted and non-impacted rockpools. Evidence from other work suggests effects may be greater sub-tidally and in sea-grass habitats where *Sargassum* can show strong recruitment. The results of this work are currently being prepared for publication.

Experiments investigating the role of native algal diversity in community resistance were conducted using a new technique developed from the work of Stachowicz et al (2004). The functional diversity of local communities was manipulated using experimental tiles. Communities were assembled with a gradient of functional diversity, from low (one algal functional group) to high (four algal functional groups). The invasion of both native taxa (*Fucus serratus* and *Enteromorpha* spp.) and the non-native species *Sargassum muticum* was observed. These experiments indicated

that functional diversity per se did not influence colonisation, but the identity of functional groups was very important. These data are in agreement with many recent publications on the role of biodiversity and point to the importance of recognising that some 'key' species or groups can have important roles in the functioning of ecosystems. In our work it was clear that loss of the functional group of canopy algae (which is probably the group most threatened by anthropogenic impacts in coastal waters) may enhance invasive processes. This work was recently published in the high profile journal of Ecology.

Paper: Arenas F., Sanchez I., Hawkins S.J., Jenkins S.R. (2007). The invasibility of marine algal assemblages: role of functional diversity and identity. *Ecology*. 87: 2851-2861.

(iii) *Caprella*

Studies on the alien caprellid, *C. mutica* found that where native and introduced species of caprellids co-occurred, both species shared the same preference for the individual structures and competition for space occurred. *C. mutica* was a superior competitor and was able to displace the native *C. linearis* at low structural diversity due to its aggressive behaviour. At higher structural diversity, however, the results suggested that communities may prevent the complete exclusion of native species, which are ecologically similar to the invader, by offering refuges within the structural architecture of the community.

Further experiments, regarding density dependent interactions between the non-native and the native caprellid using the same substrate showed that only comparatively low numbers of the non-native *C. mutica* were needed to displace significantly higher proportions of the native species. However, displacement activity was restricted when population abundances of *C. linearis* declined to relatively low densities, suggesting that *C. mutica* might not entirely displace *C. linearis* and that coexistence may occur in the field.

Kelp communities were surveyed to look for *C. mutica* in natural communities close to known established populations of *C. mutica*. In addition to collecting kelp plants, artificial collecting meshes were deployed. Removal of kelp and artificial meshes every month from April to October showed that *C. mutica* could be found on the artificial meshes but not on the kelp plants or associated epifauna. Currently we are undertaking laboratory experiments to try to elucidate why this occurred. Previous work indicates that it could be the size and morphology of structure (i.e. flat leaf like versus round filamentous) however many of the kelp plants collected did have epiphytes that had the preferred type of structure for *C. mutica* and native caprellids were found on the epiphytes attached to some of the kelp plants.

Caprella mutica has also been observed on structures close to the sea surface, whereas it has not been found on the seabed. To test this observation, a depth distribution experiment was undertaken at Dunstaffnage fish farm where there are twelve salmon cages. Artificial meshes were deployed from the surface to a depth of 40m and left for one month. Preliminary analysis showed that *C. mutica* does have a distinct depth distribution, however, we need to carry out detailed analysis to elucidate if this is a gradual decrease in numbers from the surface to the bottom or if there is a distinct depth zone in which *C. mutica* occurs.

Preliminary investigations on a possible impact of *C. mutica* as a carnivorous filter feeder on the larvae of the blue mussel *Mytilus edulis* were conducted. The experiments revealed no clear effect on either survival or settlement. Further investigation is planned for 2007 to determine whether different size classes of *C. mutica* influence survivorship of mussel larvae.

Paper: Shucksmith, R., Cook E.J., Burrows, M.T., Hughes, D.J. (submitted). Structural heterogeneity reduces competition and promotes coexistence between non-native and native caprellids. *Journal of Animal Ecology*.

Boos, K., Shucksmith, R., Cook, E.J., Gutow, L., Franke, H.-D. (in prep.) Competitive interactions between the non-native amphipod *Caprella mutica* Schurin, 1935 and its congener *C. linearis* (Linnaeus, 1767) in European coastal waters - a matter of propagule pressure?

Boos, K., Cook, E.J., Gutow, L., Franke, H.-D. (in prep.) Influence of the non-native amphipod *Caprella mutica* Schurin, 1935 on the settlement success of *Mytilus edulis* (Linnaeus, 1758)

(iv) *Styela*

Experiments have been undertaken on the effect of the alien ascidian *Styela clava* on the hard-substrate community of marina pontoons, in terms of the diversity and biomass of the community and particle clearance rate by the assemblage. The presence of *S. clava* on 15 x 15 cm panels slightly enhances biodiversity compared to panels from which *S. clava* is excluded, once assemblages reach 6 months or more in age. The primary effect is probably an increase in available area for encrusting growth. (Being attached by a narrow stalk, adult *S. clava* have a small 'footprint' but a substantial body surface that is readily colonised). However, the effect of latex-mimic *S. clava* of similar size is less pronounced, suggesting that increased available surface area is not the sole cause of enhanced biodiversity. This work is included in a PhD thesis to be submitted in September 2007.

• **Determination of tolerance limits (e.g. temperature, salinity etc.) and prediction of potential spread throughout the UK**

(i) *Caprella*

Physiological tolerances limit the distribution of marine species, with geographical ranges being set by physical characteristics that affect the rates of vital processes and survival. Temperature and salinity are often considered to be the principle variables affecting growth, reproduction and survivorship. The physiological tolerances of *Caprella mutica* were investigated in laboratory experiments. Adult *C. mutica* were exposed to a range of temperatures and salinities for 48 h. *C. mutica* were tolerant to a broad range of temperature and salinity conditions, with 100 % mortality at 30 °C (48 h LT₅₀, 28.3 ± 0.41 °C), and salinities lower than 16 ‰ (48 h LC₅₀, 18.7 ± 0.24 ‰). Although lethargic at low temperatures (2 °C), no mortality was observed, and the species is known to survive at temperatures as low as -1.8 °C. The upper LC₅₀ was greater than the highest salinity tested (40 ‰), thus it is unlikely that salinity will limit the distribution of *C. mutica* in open coastal waters. However, the species will be excluded from brackish water environments such as the heads of sea lochs or estuaries. The physiological tolerances of *C. mutica* are beyond the physical conditions experienced in its native or introduced range and are thus unlikely to be the primary factors limiting its present distribution and future spread.

Paper: Ashton, G.V., Willis, K., Burrows, M.T., Cook, E.J. (2007). Environmental tolerance of *Caprella mutica*: implications for its distribution as a non-native species. *Marine Environmental Research*.

(ii) *Perophora japonica* and *Styela clava*

Seasonal monitoring of populations of the ascidians *Styela clava* and *Perophora japonica* in Plymouth was undertaken over two years (March 2004-February 2006) to assess the possibility of adaptation or acclimation to local climatic conditions, compared to the species' phenology in the native range. *P. japonica* shows a markedly different annual cycle from that reported from Shimoda (Japan). In Plymouth, colonies show varying degrees of regression in winter, but zooids are present year-round; both asexual (terminal budding) and sexual reproduction occur from Spring to early Autumn, peaking in summer, and can be seen simultaneously in the same colony. In Japan, sexual reproduction peaks in the winter and colonies regress markedly to dormant stolons during the summer; asexual reproduction is largely restricted to the non-breeding season or to non-breeding colonies during the breeding season. It thus appears that *P. japonica* is capable of adjusting its life cycle profoundly to different local conditions, a capacity likely to enhance its scope for geographical spread in its introduced range. However, *P. japonica* does not seem to be spreading progressively in the UK; even in Plymouth, where it was first recorded at a single marina site in 1999, it has not reached neighbouring marinas.

Individuals of *S. clava* were tagged and monitored; they showed peak growth during April to June, and could live for more than 18 months, with most deaths during the winter. Analysis of a time-series of samples taken to elucidate the reproductive cycle is ongoing. Of particular interest is the apparent static northern limit of the species in Europe. We only recorded a marginal range

extension northwards from Ardrossan, where it was already present in 1981, while considerable spreading around Ireland has occurred over the same interval.

- **Use of molecular genetic markers to identify origins, vectors of introduction, and dispersal rates**

The use of molecular genetic markers to identify origins, time of introduction and potential vectors of the non-native macroalgae, *Codium* and the caprellid shrimp *Caprella mutica* has been investigated.

(i) *Codium*

We analysed worldwide samples of *Codium fragile*, including type specimens where possible, from two herbaria, the Natural History Museum London and the Ulster Museum. Many of the specimens were collected over 100 years ago, and the approach to obtaining sequence data was to use the techniques of ancient DNA analysis. We designed primers that amplified overlapping fragments of less than 180 base-pairs in length in order to work with the degraded DNA extracted from old herbarium specimens. The fragments of sequence were then joined up to complete the 350 bp chloroplast marker that we had found to be valuable for identification of subspecies. Sequencing of the herbarium material as well as freshly collected *Codium fragile* from around the world showed that there are recognized native subspecies in South Africa, New Zealand, Pacific USA, Mexico and the British Isles (subsp. *atlanticum*). Three previously unrecognized subspecies were found in China and South Africa. *Codium fragile* was originally described from Japan, which is the origin of the invasive subspecies *tomentosoides*. Under the International Code of Botanical Nomenclature, this subspecies will therefore be known as subsp. *fragile*, but here we continue to use the name *tomentosoides* to avoid confusion.

Molecular characterisation of previously misidentified herbarium specimens showed that subsp. *tomentosoides* has been colonising new habitats across the world for longer than records would indicate, in some cases by nearly 100 years, and can now be found in the ranges of all the other native subspecies detected. The invasion was often un-noticed because subsp. *tomentosoides* is cryptic relative to native strains. Of these native subspecies, the southern hemisphere taxa displayed a lower degree of endemism than those in the northern hemisphere, probably as a result of homogenisation by the Antarctic Circumpolar Current.

Of the three subspecies that have previously been regarded as invasive, subspp. *tomentosoides*, *atlanticum* and *scandinavicum*, only *tomentosoides* is actually an alien but *scandinavicum* is a synonym (i.e. its description was based on a specimen of *tomentosoides*). One of the most surprising findings was that subsp. *atlanticum*, rather than being an invasive introduction, is almost certainly a native subspecies endemic to the British Isles.

The dated and identified specimens were used to plot the spread over time of *Codium fragile* subsp. *tomentosoides* in Europe (Fig. 2). Analysis of distances (in kilometres) from the original source of primary introduction to sites of secondary introduction over time, in the Atlantic region of Europe, shows an average spread rate of 21km/year (Figs. 3&4).

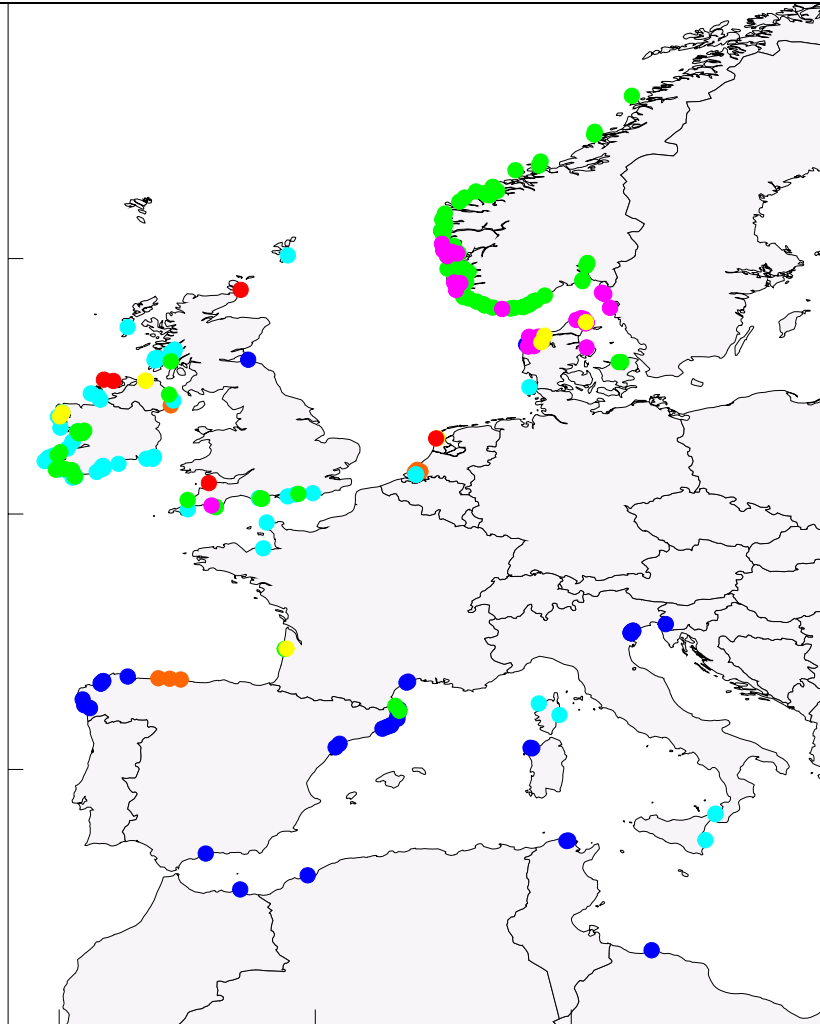


Figure 2: Spreading of *Codium fragile subsp. fragile* in Europe and the Western Mediterranean Sea (● 19th century; ● 1901-1920; ● 1921-1940; ● 1941-1960; ● 1961-1980; ● 1981-2000; ● 2001- present)

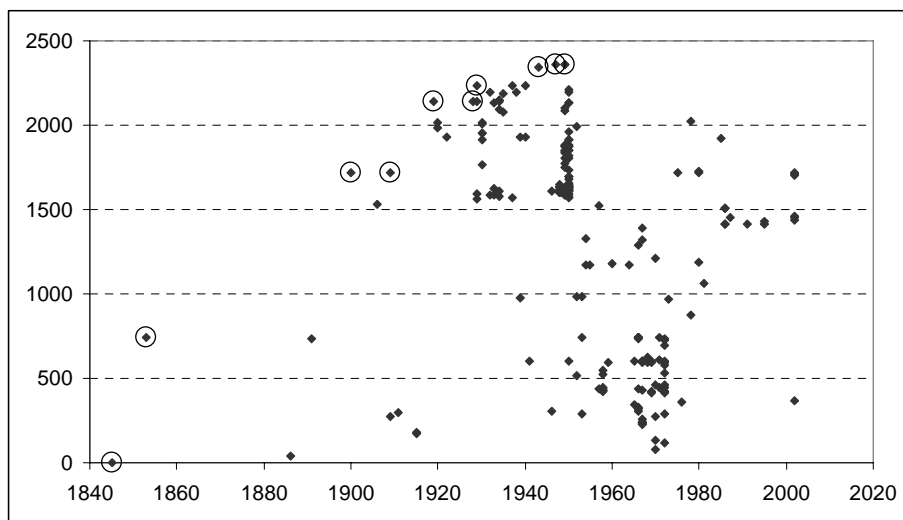


Figure 3: Distances (in kilometres) from the original source of primary introduction to sites of secondary introduction over time, in the Atlantic region of Europe. Maximum distances are highlighted and give an average spread rate of 21km/year (N=10, $R^2=0.94$).

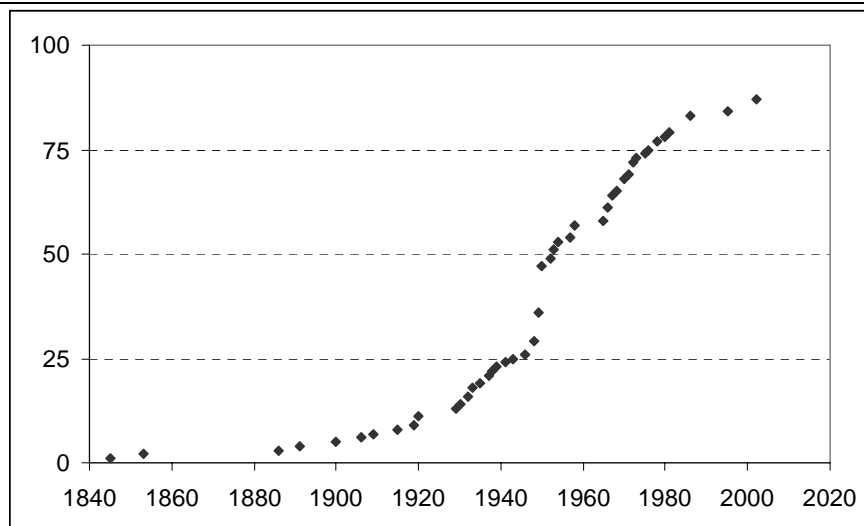


Figure 4: Cumulative number of geographical units (50x50km) occupied by *Codium fragile* subsp. *fragile* over time, in the Atlantic region of Europe.

Papers: Provan, J., Booth, D., Todd, N.P., Beatty, G. & Maggs, C.A. (2007) Tracking biological invasions in space and time: elucidating the invasive history of the green alga *Codium fragile* using old DNA. *Diversity and Distributions*. Accepted pending minor revisions.

Verbruggen, H., Leliaert, F., Maggs, C.A., Shimada, S., Schils, T., Provan, J., Booth, D., Sue Murphy, Olivier De Clerck, Eric Coppejans, E., Diane S. Littler, D.S. & Littler, M. M. (2007) Species boundaries and phylogenetic relationships within the green algal genus *Codium* (Bryopsidales) based on plastid DNA sequences. *Molecular Phylogenetics and Evolution*. Published online.

(ii) *Caprella*

DNA sequence analysis of the *C. mutica* mitochondrial cytochrome c oxidase subunit I gene (COI) was used to investigate genetic variation between native and non-native populations to help elucidate the primary and secondary introduction pathway(s) of *C. mutica* from its native range. High diversity but no genetic structure was identified in four populations in the native range. Grouping of *C. mutica* populations into native, east Pacific, and Atlantic cohorts explained the most among-region variation (59 %). The analysis identified several introduction pathways are likely to be responsible for the observed global distribution of *C. mutica*, but the pathways were least well defined between the Atlantic populations. Populations of *C. mutica* in Japan are most likely longer established and to occur within the species' native range, but were potentially not the actual source of any of the non-native populations examined in this study.

Paper: Ashton, G.V., Stevens, M.I., Hart, M.C., Green, D.H., Burrows, M.T., Cook, E.J., Willis, K.J. (submitted). Mitochondrial DNA reveals multiple northern hemisphere incursions of the highly invasive *Caprella mutica*.

(iii) *Perophora japonica* and *Styela clava*

Mitochondrial sequence information (COI) for *Perophora japonica* is currently being generated by a post-doc in Plymouth. Samples are available from the three known UK populations (including that in the Fleet, now believed to be extinct) and several French localities. Yearly mapped samples are available since 1999 from the first UK locality (Plymouth), and will allow analysis of changes in genetic diversity in this 'bridgehead' population. RAPD-PCR fingerprinting of 44 colonies collected from the same marina pontoon in Plymouth in 2000 and 2001 revealed the absence of repeated genotypes. This implies that the population was reproducing predominantly or exclusively sexually, despite the potential for this species to clone asexually by the production of dispersive terminal buds.

Generation of molecular data for *Styela clava* is complete. A global phylogeography of *Styela clava* using COI is being produced in collaboration with scientists in New Zealand (where *S. clava* was discovered in 2005) and the USA; pooling of data from the three different laboratories has produced an impressive body of data. In Plymouth, the history and inter-relationships of European populations are being investigated with a combination on COI and microsatellite data. A small-scale study of population differentiation using microsatellite data has also been undertaken, focusing on the south Devon coast. It is becoming apparent that the genetic pattern in the introduced range does not suggest a progressive front-like spread of the species by natural dispersal of larvae, rather a series of jumps, presumably mediated by human-aided long- or medium-range movements.

Paper: Dupont, L., Viard, F., Bishop, J.D.D. (2006). Isolation and characterization of twelve polymorphic microsatellite markers for the invasive ascidian *Styela clava* (Tunicata). *Molecular Ecology Notes*. 6: 101-103.

- **Potential control of the Chinese Mitten Crab in the Thames**

In December 2006, Paul Clark and Brian Smith NHM sampled the mitten crabs collected during the project, and dissected each specimen for two types of tissue. These comprised of carapace tissues such as Hepatopancreas etc and muscle. Fifty-two tissues samples from the four Thames sites were sent to Scientific Analysis Laboratories, Manchester for analysis of levels of mercury, cadmium, lead, dioxins, PAHs and PCBs.

In addition, monthly samples of crabs were collected for the Health Protection Agency and these specimens were tested for Enterobacteriaceae; *E. coli*; *Salmonella* and *Campylobacter* (because we frequently isolate these two pathogens from the river) and used in the development of methods for the characterisation of *Vibrio parahaemolyticus*. CEFAS used these samples primarily, to collect *V. parahaemolyticus* strains over time and characterise them using an epidemiological tool called pulsed field gel electrophoresis (PFGE). Samples were sent to CEFAS every month when possible, during the period of November 2005 - November 2006. Furthermore data on temperature and salinity of the waters was also given and towards the end of the sampling period, water samples were also collected for CEFAS to help with further investigations.

On 16 April 2007, a workshop will be hosted by the Department of Zoology, NHM to discuss the suitability of Thames mitten crabs for human consumption under the guidance of Mr Jon Averbs, London Port Heath Authority. Those presenting results will be Dr Grant Stentiford & Ms Sariqa Wagley of CEFAS Weymouth Laboratory, Dr Susanne Surman, London Food, Water & Environmental Microbiology Laboratory, Health Protection Agency, Colindale and Prof. Phil Rainbow and Paul Clark NHM, London.

A number of mature *Eriocheir sinensis* have also been collected by Philine zu Ermgassen, Aquatic Ecology Group, Department of Zoology, University of Cambridge, for preliminary trials on the impacts of Chinese mitten crabs on the invasive Zebra mussel *Dreissena polymorpha*. These mussels are another common invasive species found in the River Thames. This work is still in progress and will resume in the coming autumn. This project will also investigate the impacts of mitten crab predation on *Corbicula fluminea*. Thesis title is: "Interactions between invasive species in British Freshwaters"

- **Production of a case-study, as required by the EU Convention on Biological Diversity**

Case studies for *Caprella mutica*, *Sargassum muticum*, *Eriocheir sinensis*, *Perophora japonica* and *Codium fragile* subsp. *fragile* have been completed (Annex I) and submitted to the Convention on Biological Diversity secretariat for dissemination through the Clearing-House-Mechanism and website (www.biodiv.org).

- **Development of an action plan and conservation strategy**

The Marine Aliens team has provided advice to government and non-governmental agencies on developing a UK action plan and conservation strategy for invasive non-native species through a variety of pathways including:

- (i) UK Biodiversity Research Advisory Group (UK BRAG) – E. Cook represented the Marine Aliens team on the ‘Non-Native Species (NNS) Sub-Group and assisted in the development of the NNS objectives, position statement and in the writing of a UK Research Strategy for Non-Native Species. This strategy document was launched at the UK BRAG Annual meeting in July 2005 and can be found at http://www.jncc.gov.uk/pdf/BRAG_NNS_NonNativeSpeciesResearchStrategy.pdf. The sub-group included representatives from JNCC, DEFRA, Scottish Natural Heritage (SNH), Natural England (NE), Centre for Ecology and Hydrology and Royal Botanic Gardens, Edinburgh.
- (ii) GB Invasive Non-native species framework strategy – E. Cook will provide a response to the consultation document that was released in Feb 2007. The response deadline is the 23 May 2007.
- (iii) All Ireland Invasive Species Group Steering Committee – C. Maggs is a of the member of this cross-border body which is currently preparing action plans for existing and potential invasives in Ireland
- (iv) ICES/IOC/IMO Working Group on Ballast Water and Other Ship Vectors – E. Cook represented the Marine Aliens team on this working group in 2006 and has provided regular updates through the UK representative on this working group (Tracy Edwards, JNCC).
- (v) Joint Nature Conservancy Council (JNCC)
- (vi) Scottish Executive – E. Cook represents the Marine Aliens team on the invasive species working group (2005 – Current). The working group includes representatives from the Scottish Executive, the Great Britain Secretariat for Non-native species, SNH, JNCC, SEPA and Fisheries Research Services.
- (vii) Argyll and Bute Invasives Forum – E. Cook represents the Marine Aliens team on this forum (2006 – Current)
- (viii) Scottish Wildlife Trust (SWT) – E. Cook represents the Marine Aliens team on the Conservation Committee for the SWT (2006 – Current).
- (ix) Sargassum Working Group (Scottish Natural Heritage) – E. Cook represents the Marine Aliens team on this working group.

It is envisaged that by raising the profile of marine non-native species at various levels in the government and non-governmental sectors and by supporting this advice with scientific evidence, the Marine Aliens programme will be able to significantly influence the development of the UK action plan and conservation strategy for invasive non-native species.

- **Publication of information via dedicated *MarLIN* web pages**

The Marine Aliens Web pages are complete and the website has received almost 67,000 visitors over the last 3 years, with an average of 67 hits day⁻¹ (Table 1). A home page shows all the elements of the site including species pages, background to the project, a section on ‘biological invasions’, progress reports and a links page. All these are populated to a greater or lesser extent. The species pages are reached via text links or purpose-drawn graphic icons. They show images and distribution maps, and link to more images and videos, interactive maps (in production) and *MarLIN* species information pages. The pages are built around databases and champions are able to log on, enter information and upload images. All online information is, therefore, under the control of species champions and is easily and instantly updated. Information for *Caprella mutica* and *Eriocheir sinensis* has been uploaded and is online and a basic information summary has been prepared for all species. Images are online for all species. In addition, the Marine Aliens Web pages are to be archived by the British Library.

Table 1. Summary Web statistics for the Marine Aliens Web site

Parameter	Number
Total visits	65977
Average hits per day	67
Total Visitors	8712
Average Visitors Per Day	8
Average Time Spent (seconds)	142
Average PageViews per visitor	2.65
Average Downloads per visitor	0.04
Average Data Transferred per Visitor (Kb)	176.2
Total Uniq IPs	3297
Visitors Who Visit Once	2562
Visitors Who Visit more than Once	735

- **Increase public awareness and understanding of the issue with articles in appropriate magazines and the provision of publicity material at centres, such as ports/harbours, marinas, the Natural History Museum and public aquaria**

(i) Marine Aliens Leaflets, Posters & Underwater ID Guides

Publicity material in the form of leaflets, posters and underwater ID guides presenting information on the seven EF Alien species and their distribution has been produced and distributed. The publicity material was produced to raise public awareness of marine alien species, to assist in their identification and to help to determine the distribution of the seven target species.

Matched funding for production of the publicity material was obtained from Scottish Natural Heritage (SNH) and funding from JNCC (Feb 2006) enabled a second batch of 10,000 leaflets to be produced. The leaflets and posters have been distributed to government and non-government organisations, marinas, ports, Natural History Museum, public aquaria, local wildlife groups, schools and sailing/kayaking clubs throughout the UK. Over 3,000 Marine Aliens posters have been distributed from the Darwin Centre, Natural History Museum, London.

Underwater ID guides have been distributed to SeaSearch participants, project partners and project participants. Guides have also been distributed to participants in *MarLIN*'s volunteer recording scheme and at conferences and educational events.

(ii) Conference Session & Publication of Special Issue in the Scientific Journal, Hydrobiologia

6th International Crustacean Congress, Glasgow 18-22 July 2005 – Paul Clark and Elizabeth Cook co-organised a session on 'Invasive Crustacea' and 12 papers presented at this meeting will be published in a special issue of the scientific journal, *Hydrobiologia* (release date 2007, Eds: E. Cook and P. Clark). Invited speakers attending the meeting were Dr G. Ruiz (USA), Dr B. Galil (Israel) and Dr J. Sundet (Norway).

(iii) Scientific Papers:

Arenas, F., Bishop, J.D.D., Carlton, J.T., Dyrinda, P.J., Farnham, W.F., Gonzalez, D.J., Jacobs, M.W., Lambert, C., Lambert, G., Nielsen, S.E., Pederson, J.A., Porter, J.S., Ward, S., Wood, C.A. (2006). Alien species and other notable records from a rapid assessment survey of marinas on the south coast of England. *Journal of the Marine Biological Association*. 86: 1329-1337.

Arenas F., Sanchez I., Hawkins S.J., Jenkins S.R. (2007). The invasibility of marine algal

- assemblages: role of functional diversity and identity. *Ecology*. 87: 2851-2861
- Ashton, G.V., Boos, K., Shucksmith, R., Cook, E.J. (2006). Rapid assessment of the distribution of marine non-native species in marinas in Scotland. *Aquatic Invasions*. 4: 209-213.
- Ashton, G.V., Boos, K., Shucksmith, R., Cook, E.J. (2006). Risk assessment of hull fouling as a vector for marine non-natives in Scotland. *Aquatic Invasions*. 4: 214-218.
- Ashton, G.V., Willis, K., Burrows, M., Cook, E.J. (In Press). Environmental tolerance of *Caprella mutica*: implications for its distribution as a non-native species. *Marine Environmental Research*.
- Ashton G.V., Willis, K.J., Cook, E.J. (in press). Global Distribution of the caprellid amphipod *Caprella mutica* (Crustacea, Caprellidae) with a detailed account of the distribution in Scotland. *Hydrobiologia*.
- Ashton, G.V., Stevens, M.I., Hart, M.C., Green, D.H., Burrows, M.T., Cook, E.J., Willis, K.J. (in prep) Mitochondrial DNA reveals multiple northern hemisphere incursions of the highly invasive *Caprella mutica*.
- Boos, K., Shucksmith, R., Cook, E.J., Gutow, L., Franke, H.-D. (in prep.) Competitive interactions between the non-native amphipod *Caprella mutica* Schurin, 1935 and its congener *C. linearis* (Linnaeus, 1767) in European coastal waters - a matter of propagule pressure?
- Boos, K., Cook, E.J., Gutow, L., Franke, H.-D. (in prep.) Influence of the non-native amphipod *Caprella mutica* Schurin, 1935 on the settlement success of *Mytilus edulis* (Linnaeus, 1758)
- Clark, P.F. (2006). *Eriocheir sinensis* H. Milne Edwards: 1853 or 1854 – Grapsidae or Varunidae? *Aquatic Invasions*. 1(1): 17-27.
- Clark, P.F., Abdul-Sahib, I.M., Al-Asadi, M.S. (2006) The first record of *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) from the Basrah Area of Southern Iraq. *Aquatic Invasions*. 1(2): 51-54.
- Cook, E.J., Willis, K.J., Lozano-Fernandez, M. (in press). Survivorship, Growth and Reproduction of the Invasive *Caprella mutica* Schurin (Crustacea: Amphipoda). *Hydrobiologia*.
- Cook, E.J., Arsenault, G., Ashton, G.V., Barnette, P., Clark, P., Coutts, A., Gollasch, S., Hewitt, C., Liu, H., Minchin, D., Ruiz, G., Shucksmith, R. (submitted). Marine Biodiversity Hotspots under Threat from Exotic Escapes: A call for action. *PNAS*.
- Dupont, L., Viard, F. Bishop, J.D.D. (2006). Isolation and characterization of twelve polymorphic microsatellite markers for the invasive ascidian *Styela clava* (Tunicata), *Molecular Ecology Notes*. 6: 101-103.
- Provan, J., Booth, D., Todd, N.P., Maggs, C. A. Tracking biological invasions in space and time: elucidating the true invasive history of the green alga *Codium fragile* using old DNA. *Molecular Ecology*. Invited resubmission.
- Robbins, R.S., Sakari, M., Baluchi, S., Clark, P.F. 2006. The occurrence of *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) from the Caspian Sea region, Iran. *Aquatic Invasions*. 1(1): 32-34.
- Shucksmith, R., Cook E.J., Burrows, M.T., Hughes, D.J. (in prep). Increasing structural diversity reduces competition and promotes coexistence between non-native and native caprellids.
- Verbruggen, H., Leliaert, F., Maggs, C.A., Shimada, S., Schils, T., Provan, J., Booth, D., Murphy, S., De Clerck, O., Coppejans, E., Diane S. Littler, D.S. & Littler, M. M. (2007) Species boundaries and phylogenetic relationships within the green algal genus *Codium* (Bryopsidales) based on plastid DNA sequences. *Molecular Phylogenetics and Evolution*. Published online.
- Willis K.J., Cook, E.J. Lozano-Fernandez, M. (2004). First record of the alien caprellid amphipod, *Caprella mutica*, for the U.K. *Journal of the Marine Biological Association*. 84: 1027-1028.

(iv) Book Chapters

- Cook, E.J., Ashton, G.V., Campbell, M., Coutts, A., Gollasch, S., Hewitt, C., Liu, H., Minchin, D., Ruiz, G. Shucksmith, R. (accepted). Non-native Aquaculture Species Releases: Implications for Aquatic Ecosystems. In: *Aquaculture in the Ecosystem*.
- Ashton, G.V., Boos, K. (submitted). Taxonomic details for addition to key and line drawing of *Caprella mutica* to be included in new edition of Hayward and Ryland (Eds) *Handbook of Marine Fauna of North-West Europe*. Invited submission.

Caprellid & Mitten Crab photos to be included in a book about introduced species to the Norwegian fauna. The author is Dr. Kjetil Bevanger who is Senior Research Scientist at NINA - Norwegian Institute for Nature Research.

(v) PhD Thesis

Ashton, G.V. (2006). Distribution and dispersal of the non-native caprellid amphipod, *Caprella mutica* Schurin 1935. Aberdeen University. pp. 180.

(vi) Editorial Board

Clark, P.F. and Cook, E.J. (2006 to present). Editorial board for online journal 'Aquatic Invasions'. <http://www.aquaticinvasions.ru/>

(vii) International & National Conference Presentations & Posters:

Arenas, F. Biological Diversity and Invasiveness (2006). ESF LESC Exploratory Workshop - Invasion of European Shores by Sargassum Muticum: Research Integration towards the Future. Convened by Aschwin H. Engelen and Rui O. Santos. Faro Portugal, November 2006.

Arenas, F. (2006) El papel de la identidad y diversidad funcional en la resistencia a la invasión en comunidades de microalgas, SEF – Sociedad Española de Ficología, Spanish Phycological Society – Annual Meeting. Madrid. December 2006.

Arenas, F., Sanchez, I., Hawkins, S.J., Jenkins, S.R. (2005). MARBEF Theme2 Workshop: Ecosystem stability vs. marine biodiversity: The role of functional diversity on the stability of macroalgal assemblages. Tavira Portugal

Arenas, F. (2005). MARBEF BIOFUSE Workshop: Susceptibility of marine algal assemblages to invasion: the role of functional diversity. Dublin, Ireland

Arenas, F., Jenkins, S.R., Hawkins, S.J. (2005). Susceptibility of marine algal assemblages to invasion: the role of functional diversity (Oral presentation). MARBEF Workshop. Aquatic invasive species and the functioning of European coastal ecosystems. Alfred Wegener Institute (AWI), Island of Sylt, Germany, 27-30 Jan 2005.

Ashton, G.V., Cook, E.J., Burrows, M.T. Willis, K.J. (2006). Mariculture – providing a year round refuge for the non-native amphipod, *Caprella mutica*. AQUA2006, World Aquaculture Society, Florence, Italy.

Ashton, G.V., Cook, E.J., Willis, K.J., Burrows, M.T. (2006). Secondary vectors of the introduced marine amphipod *Caprella mutica* on the west coast of Scotland. ICIAS, Florida

Ashton, G.V., Cook E.J., Willis, K.J., Burrows, M.T. (2006). Hitch hikers- unwanted passengers on a Northern Sea Passage. British Council Tromso Conference

Ashton, G.V., Willis, K.J, Cook, E.J. and Burrows, M.T. (2005). Distribution of *Caprella mutica*, an introduced skeleton shrimp (Amphipoda, Caprellidae), in Scotland and Worldwide (Abstract). ICC6, Glasgow, U.K.

Ashton, G.V., Stevens, M.I, Green, D., Hart, M., Willis, K.J., Burrows, M.T., Cook, E.J. (2005) Introduction pathways of the Japanese skeleton shrimp, *Caprella mutica*. 8th Annual New Zealand Molecular Ecology Meeting, Canterbury, New Zealand.

Ashton, G.V., Willis, K.J., Cook, E.J., Vader, W., Tierney, D., Chapman, E., Fenwick, G. Takeuchi, I., Platvoet, D. (2004). Global distribution of the invasive marine amphipod *Caprella mutica*. (Abstract). International Aquatic Invasive Species Conference, Ennis, Ireland. 20 – 24 Sept 2004.

Ashton, G.V., Willis, K., Cook, E.J., Tierney, D., Vader, W. (2004). European distribution of the non-indigenous marine amphipod, *Caprella mutica* (Poster). Annual Symposium of the British Ecological Society, Ecology without frontiers: Environmental challenges across Europe, University of Exeter, 5-7 April, 2004.

Ashton, G.V., Willis, K.J., Cook, E.J., Tierney, D., Vader, W. (2004). European distribution of the non-indigenous marine amphipod, *Caprella mutica* (Poster). Spring meeting of the Scottish Marine Group, Stirling University, 10 March, 2004.

Nauwelaerts, S., Michel, K., Boos, K., Stamhuis, E. (2007). Is the Japanese skeleton shrimp

- Caprella mutica a filter feeder? II. Fluid mechanics. Experimental Biology Conference, Glasgow. April 2007.
- Booth, D., Todd, N.P., Maggs, C., Provan, J. (2005). Tracking biological invasions in space and time: elucidating the invasive history of the green alga *Codium fragile* ssp. *tomentosoides* using old DNA. Annual Ecological Genetics Group Meeting, UK, March 2005.
- Cook, E.J. (2006). Climate change and bioinvasions – How safe are our oceans? Invited Speaker. Scottish Marine Group, Stirling. October 2006.
- Cook, E.J., Shucksmith, R., Ashton, G.V. (2006). Fatty Acid Composition of the Invasive Caprellid, *Caprella mutica* (Crustacea: Amphipoda) on the west coast of Scotland: trophic and environmental implications. ICIAS, Florida
- Cook, E.J., Willis, K.J., Clark, P.F., Maggs, C., Arenas, F., Hiscock, K., Bishop, J.D.D. Marine Aliens - Conserving native biodiversity by raising awareness of invasive species. Poster for 6th International Crustacean Congress, Glasgow 18-22 July 2005
- Cook, E.J. (2005). Marine Aliens – Conserving native biodiversity by raising awareness of non-native species. Scottish Biodiversity Forum, March 2005.
- Cook, E.J., Willis, K.J., Ashton, G.V., Clark, P.F., Maggs, C., Arenas, F., Bishop, J.D.D., Hiscock, K. (2004). Marine Aliens - Conserving Native Biodiversity by Raising Awareness of Invasive Species (Abstract). International Aquatic Invasive Species Conference, Ennis, Ireland. 20 – 24 Sept 2004.
- Cook, E.J., Willis, K.J., Ashton, G.V. (2004). Population dynamics & development of the invasive caprellid amphipod *Caprella mutica* (Abstract). International Aquatic Invasive Species Conference, Ennis, Ireland. 20 – 24 Sept 2004.
- Clark, P.F. (2007). Mitten crabs. Royal Society funded workshop on the identification of marine invertebrates held at the University of the Western Cape, South Africa, January 2007.
- Crowe, T., Arenas, F., Benedetti-Cecchi, L., Hawkins, S., Jenkins, S., O'Connor, N., Maggi, E. (2006). Biodiversity and the Functioning and Stability of Ecosystems: a Temperate Reefs Perspective. 7th International Temperate Reef Symposium Santa Barbara, CA USA, June 2006.
- Dupont, L., Viard, F., Hallas, P., Wood, C., Bishop, J.D.D. (2005) Molecular tools to track three alien ascidians in NW Europe (presentation and poster). International Invasive Sea-squirt Conference, WHOI Massachusetts, USA, 21-22 April
- Shucksmith, R., Cook, E.J., Burrows, M.T., Hughes, D.J. (2006) Does structural diversity increase the invasibility of subtidal communities by the non-native amphipod *Caprella mutica*? ICAIS, Florida
- Shucksmith, R., Cook, E.J., Burrows, M.T., Hughes, D.J. (2005). Structural diversity: Does it increase the invasibility of subtidal communities by the non-native amphipod *Caprella mutica*? (Abstract) BES Annual Conference, UK
- Shucksmith, R., Cook, E.J., Burrows, M.T., Hughes, D.J. (2005). Does greater structural biodiversity increase the susceptibility of a community to invasion? (Abstract). ICC6 Glasgow, U.K.

(viii) Articles:

- Bishop, J.D.D., Wood, C.A. (2005). *Styela clava*. Shellfish News No. 20, p. 20.
- Bishop, J.D.D., Wood, C.A. (2005). *Styela clava*. The Grower (June Issue).
- Cook, E.J. (2006). New waterproof ID guide launched for marine invasive species. The Grower. Association for Scottish Shellfish Growers Newsletter. September Issue. p6.
- Cook, E.J., Shucksmith, R., Ashton G.V. Willis, K.J. (2005). Invasion of the Skeleton Shrimps. Fish Farming Today.
- Cook, E.J. (2004) Have you seen these aliens? – MBA News (October 2004)
- GloBallast Newsletter (vol 16) - Suspect Species in Scottish Seas (1 March 2004)
- Oban Times Marine aliens outside Oban (22 March 2007)
- Oban Times - Alien species comes under the microscope at Dunstaffnage (15 July 2004)
- Shucksmith, R. Cook, E.J. (2005). Impacts of non-native species in the UK. Marine Conservation Magazine. Autumn Edition.
- Sunday Times - Alien invasion is wiping out native sea life - (11 April 2004)

(ix) Exhibitions:

Public display 'Marine Aliens UK' – Non-native species Stakeholder Forum, Edinburgh, May 2007.

Public display at Dynamic Earth (Edinburgh) as part of the 'Making Tremors' science event (March 2007) sponsored by Scottish Executive

Public Display 'Marine Aliens', Scottish Association for Marine Science, Open Day, March 2006 and 2007.

Public display 'Is that an Alien on the Bottom of Your Boat?', Marine Biological Association, three days during National Science Week, March 2006

Aliens Display - Glasgow Museums Resource Centre (2005)

(x) Public talk:

Bishop, J. "Alien visitors", Marine Biological Association Resource Centre, Plymouth, March 15th 2005.

Bishop, J. 'The Tamar's Gift to Europe: The Leathery Seasquirt', Plymouth Dome, Tamar Coastal Festival, 23 July 2005

Clark, P.F. Seminar on *Eriocheir sinensis* for Scarborough Centre for Coastal Studies Hull University 25 January 2006.

Clark, P.F. Presentation on mitten crab project for Darwin Centre Live, The Natural History Museum, London, 6 February 2006

Clark, P.F. Thames mitten crabs (Invited Speaker). Shellfish Association of Great Britain Annual Conference 22 May 2007.

Cook, E.J. Marine Invasions and Likely Vectors – Lochaber Yacht Club, March 2007.

Cook, E.J. Marine Invasions and Climate Change – Firth of Clyde Forum, February 2007.

Cook, E.J. Marine Invasions and Climate Change – Scottish Marine Group Meeting, Stirling University (2006)

Maggs, C. The study of phycology: from Hippocrates to Linnaeus. Public lecture, QUB, May 2005.

Shucksmith, R. Marine Aliens in Scotland – Dynamic Earth Event, March 2007

(xi) Television:

Bishop, J.D.D. Interview on alien species survey, BBC Spotlight (Guernsey), 31 August 2005.

Clark, P.F. TV Tokyo, 25 August 2006

Clark, P.F. The Inside Out Show, BBC, October 2006

Clark, P.F. Mitten crab project aired on Nipon TV, Japan 2 February 2006

Clark, P.F. Mitten crab project aired on Channel 4 News 6 February 2006

Clark, P.F. Mitten crab project aired on BBC 1 News 6 February 2006

Clark, P.F. Exploitation of Chinese mitten crabs in River Thames. Fuji Television News Network, Japan. 17 January 2005.

Clark, P.F. Tales from the Country, Invasive species including Chinese Mitten crabs. ITV Channel 3. Broadcast 15 April 2004.

(xii) Radio:

Bishop, J.D.D. Interview on alien species survey, BBC Radio Guernsey, 31 August 2005.

Cook, E.J. Falklands Programme – Invasive Species – Skeleton Shrimps. BBC World Service (April 2004).

Clark, P.F. Live from the Thames interviewed by Big George on BBC Three Counties Radio 6 February 2006

Clark, P.F. Chinese mitten crabs in the Thames. LBC 97.5 FM, breakfast programme with Paddy O'Connell, 27 March 2005.

(xiii) Student Training:

PhD

- Karin Boos (SAMS & Alfred Wegener Institute, Helgoland, Germany) – Mechanisms of a successful immigration from north-east Asia: settlement dynamics, competitive ability and anti-predatory strategies of *Caprella mutica* Schurin 1935 in European coastal waters (2005 – 2008)
- Richard Shucksmith (NERC CASE Award) - Biological Invasions: The role of biodiversity in determining community susceptibility to invasion (2004 – 2007).
- Gail Ashton (NERC) – Biological Invasions – Quantifying the impact of alien species on marine ecosystems, using the introduction of the amphipod, *Caprella mutica* to the west coast of Scotland as a case study (2003 – 2006). Gail successfully defended her viva in November 2006 and has joined Dr Greg Ruiz as a post-doctoral researcher at the Marine Invasives Research Centre, Smithsonian Institute, USA.
- Signe Nielsen (University of Plymouth scholarship with MBA as CASE analogue): The role of biodiversity in ecosystem functioning: seston–suspension feeder trophic interactions and the effect of non-native species; thesis due September 2007.

MSc

- Andrew Steele (Heriot Watt University & SAMS) – Assessing the effectiveness of GIS in monitoring the dispersal of non-native species in the UK (2004).
- Mike Dowell (University of Plymouth) – Local patterns of microsatellite diversity in the non-native ascidian *Styela clava*, introduced from the NW Pacific (2006)

MRes

- Paul Hallas (University of Plymouth) – Patterns of introduction and spread of the invasive ascidian *Styela clava*: evidence from mitochondrial sequence data (2005)
- Emma Snowden (University of Plymouth) – Development of a rapid assessment tool to monitor the prevalence of non-native species in harbours and marinas (2006)

BSc (Hons) Dissertation

- A. Lecca Martinez (UHI Millennium Institute) – What makes a successful invader? (2007)

(xiv) Education Partnerships:

The 'Alien Invaders and Climate Change Indicators' project was devised by the MBA in collaboration with Holbeton Primary School, Plymouth. Initially funded by The Royal Society, its aim was to teach children from local primary schools to become 'Alien Detectives' and survey the local shore for marine aliens and climate change indicator species. Since its inception in 2005, over 400 primary school children have been involved. The Marine Aliens Web pages link to the 'Alien Invaders and Climate Change Indicators' project.