Management of Biological Invasions (2014) Volume 5, Issue 2: 85–96
doi: http://dx.doi.org/10.3391/mbi.2014.5.2.02

Research Article

Native and non native marine biofouling species present on commercial vessels using Scottish dry docks and harbours

Tracy McCollin* and Lyndsay Brown

Marine Scotland Science, Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9DB, UK

E-mail: *Tracy.McCollin@scotland.gsi.gov.uk* *(TMC),* *Lyndsay.Brown@scotland.gsi.gov.uk* *(LB)*

**Corresponding author*

Received: 28 February 2014 / Accepted: 8 May 2014 / Published online: 6 June 2014

Handling editor: Vadim Panov

Abstract

Biofouling samples from the hulls of commercial vessels using Scottish dry docks and harbours were collected to investigate which species are being transported into Scottish waters. During 2009 – 2012 a total of 29 vessels were surveyed in three dry docks and a dive team was used to sample a further six vessels at two busy North Sea harbours. The vessels were representative of those servicing the North Sea oil industry e.g. tugs, supply and safety stand by vessels and provide a good indication of the type of fouling found on vessels that typically trade in Scottish coastal waters. The biofouling consisted of typical North Sea species and four established non native species, *Jassa marmorata, Caprella mutica*, *Austrominius modestus* and *Amphibalanus amphitrite* were recorded. No new non native species were recorded during this study.

Key words: biofouling, dry dock, non native species, Scottish waters, hulls, vectors

Introduction

The transport of non native species *via* ballast water and biofouling has long been recognised (Carlton 1985; Eno et al. 1997; Gollasch 2002) and international management measures of these vectors such as the International Maritime Organization's (IMO) Ballast Water Management Convention (BWMC) and Biofouling Guidelines have been developed with the aim of reducing the risk of introducing non native species (IMO 2005; MEPC 2011). The BWMC was adopted in 2004 but has not yet been ratified and the Biofouling guidelines agreed by the IMO in 2011 are voluntary and contain a series of practical measures and advice that should be taken into account by the shipping industry when aiming to manage the risk of introducing non native species *via* this vector.

A number of studies worldwide have examined which species are transported as biofouling on recreational and commercial vessels (Coutts and Taylor 2004; Davidson et al. 2009; Drake and Lodge 2007; Floerl and Inglis 2005; Sylvester and MacIsaac 2010). Aspects such as the speed of the vessel (Coutts et al. 2010), age of antifouling paint (Floerl et al. 2005), harbour design (Floerl and Inglis 2003) type of vessel (Davidson et al. 2009) and time spent at anchorage (Davidson et al. 2008) have all been examined as potential risk factors. Many of these risk factors have been incorporated into the IMO Biofouling guidelines, which outline methods of reducing the amount of biofouling on vessels that should be taken into account during the operation and maintenance of vessels.

The UK supported the development of these guidelines but there is currently limited knowledge regarding which species are being transported into UK waters *via* biofouling and whether particular vessels e.g. recreational or commercial, or voyages e.g. UK based or international, are of higher risk of introducing non native species. A study carried out by Ashton et al. (2006a) ranked the level of fouling of recreational vessels in ten marinas in Scotland using an index developed by Floerl et al. (2005) and found that 59% of the yachts surveyed had macrofouling suggesting that vessels of this type posed a high risk of moving non native species around UK waters. Ashton et al. (2006b) also carried out a rapid assessment to identify whether seven non native species known to be present at other locations in the UK were present in the ten marinas surveyed. Seven of these marinas had one or more of the target species present suggesting that recreational boating is an important vector for the spread of non native species. However, there have been no studies carried out in the UK to examine fouling on commercial vessels. This study aimed to record the species found on vessels arriving in Scotland by 1) visiting dry docks and 2) using a dive team to collect samples from vessel hulls whilst in harbour. Additional information regarding the voyage and maintenance history of the vessel was collected to assess whether certain vessels on certain routes may pose a higher risk of introducing non native species into UK waters. This information could then be used to inform the management of biofouling to reduce the risk of introducing non native species.

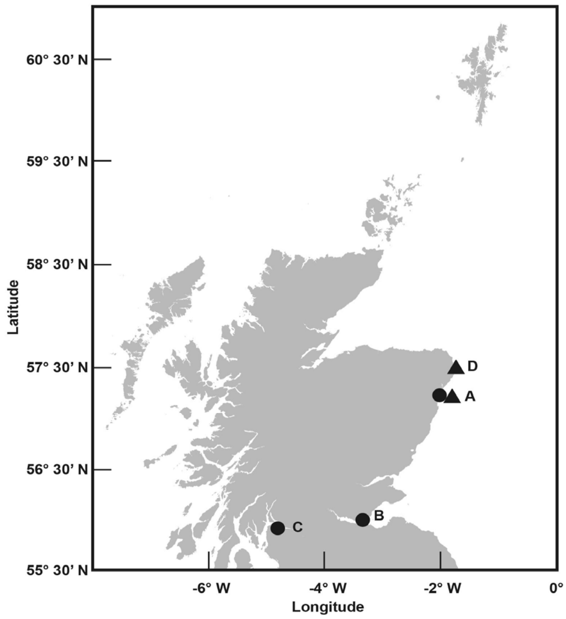

Figure 1. Location of dry docks (●) at Aberdeen (A), Edinburgh (B) and Garval Clyde in Greenock (C) and harbours used for the dive surveys (▲) at Aberdeen and Peterhead (D).

Materials and methods

Dry dock sampling sites

Three dry docks in Scotland were visited between 2009 and 2012 at Aberdeen (A) and Leith (B) on the east coast and at Garval Clyde in Greenock (C) on the west coast (Figure 1). The dry docks on the east coast were similar in size with Aberdeen measuring 112 m × 21 m × 6.5 m and Leith 168 m × 21 m × 7.7 m. Garval Clyde, on the west coast, was the largest at 200 m long and able to accommodate vessels of 20 m beam. Docking schedules were provided by dry dock personnel to enable staff from Marine Scotland Science (MSS) to organise sampling trips. A questionnaire was used to obtain information on each vessel. This included vessel type, size, trade pattern, previous dry docking information, work carried out during the current docking and the type of antifoulant paint used.

Dive team sampling sites

The size of the dry docks meant that the vessels using them tended to be small, coastal vessels that traded in the North Sea. In order to sample larger, ocean going vessels the MSS dive team undertook sampling of vessels in Aberdeen and Peterhead harbours (Figure 1). Docking schedules and voyage information obtained *via* the harbour masters and shipping agents were used to select vessels that had been trading outside the North Sea and permission was sought from the shipping agents and master of the vessel to carry out the sampling.

Sample collection

A sampling methodology was designed, as outlined below, to collect samples in a semi-quantitative manner. This methodology was used, with some adaptations, in the dry docks and by the dive team. However, it became apparent during the field work that, for a number of reasons, this methodology could not always be implemented as planned. The basis of the methodology remained the same but was altered as necessary depending on circumstances as described below.

To collect samples from vessels in dry dock MSS staff would enter the dry dock as soon as it was drained of water and conduct an initial visual survey to assess the overall fouling of the vessel. This inspection would identify areas where fouling was likely to be present i.e. areas of damaged paintwork and structures on the vessel e.g. stabilisers, that may provide protected niche areas for fouling and for any obvious differences in fouling between the port and starboard sides. Attempts were made to assign a fouling rank according to Floerl et al. (2005) but it was not always possible to carry out this initial inspection in a systematic manner. In most cases the wash down of the vessel with high pressure hoses would begin immediately after the dock was drained, which prevented inspection of all fouled areas. Also it was often dark by the time the dock was drained so the inspection had to be carried out by torchlight. In some instances staff were not able to enter certain parts of the dock for safety reasons.

Structures and areas on each side of the vessel identified as having fouling were targeted to obtain samples. This was carried out either from ground level where the structures could be reached easily or with use of an elevated work platform to allow MSS staff to reach areas further up the hull. The aim of the sampling methodology was to obtain samples at intervals along the length of each side of the hull and to target niche areas where fouling may have built up. Using a method similar to that developed by Hewitt and Martin (1996, 2001) for sampling hard substrates a quadrat of 20 by 20 cm (rather than the 0.10 m^2 used by Hewitt and Martin) was placed over the fouling present at the sampling point and photographed. This provided a record of the fouling *in situ* and an estimate of the percentage of fouling at that point. Samples of fouling were removed with paint scrapers and stored in small tubs. It was not always possible to sample both sides of the vessel as in some instances there was insufficient room for the elavated work platform to manoeuvre or dock staff were already washing down or working on sections of a vessel. Owing to differences in vessel structure and design it was not possible to sample from identical areas on each one.

The dive team also aimed to sample along each side of the vessel, targeting niche areas and collecting samples in numbered zip lock plastic bags. A video camera was used to record what the divers were seeing. The team encountered a number of problems mostly related to the very turbid water, particularly in Aberdeen Harbour, which meant that they were working in extremely poor visibility. Dive time was also restricted owing to vessel movements in the harbour and they were often requested to surface and get back to the safety of the support vessel while other vessels were passing by. There was also limited time to sample the vessels as the team had to fit in with the, typically very short, docking schedule of the vessels. Shut down procedures on the vessel necessary for the safety of the divers could only be implemented when this would not delay the vessel. This tended to limit the choice to seismic survey vessels which spend extended periods of time out at sea but, when they do come into port, are alongside for a few days. However, seismic survey vessels spend the majority of their time in deep waters away from the coast and are not so prone to fouling. Also, the vessels sampled were either new or had recently applied antifouling paint.

The dive team had limited success in collecting samples and those that were collected did not often contain enough material for analysis. These samples were therefore excluded from further examination and the study focussed on the samples collected from the dry docks.

Treatment of samples

Samples of fouling were removed with paint scrapers, stored in small tubs (dry docks) or numbered plastic bags (dive survey) and fixed in 4 % formalin as soon as possible (within an hour of collecting the sample). After fixation all samples were left in a fume hood for a minimum of one week. The formalin was then washed off by thoroughly rinsing the samples in a sieve (100 µm) under running tap water. All samples underwent an initial sort to group together the various types of fouling organisms collected. Sub samples of each were stored separately in small glass vials (7 or 15 ml) and preserved in 70 % ethanol.

Sample analysis

Specimens were identified to species level, where possible, or genus level using a Leica MZ75 stereo microscope and relevant keys (Chambers and Muir 1997; Conlan 1989; Hayward and Ryland 1995; Lincoln 1979). Identifications were confirmed by cross checking between MSS analysts or by sending samples and photographs to other taxonomic experts. The presence of algae was noted but no further identification was undertaken.

Results

A total of 29 vessels were surveyed in dry docks, 19 in Aberdeen dry dock (one vessel was sampled twice, once in 2009 and once in 2011), 7 in Edinburgh and 3 in Garval Clyde (Figure 1 and Table 1). Five of these vessels had minimal biofouling consisting mainly of a biofilm layer with very little macrofouling. Samples were not collected from these vessels and they were

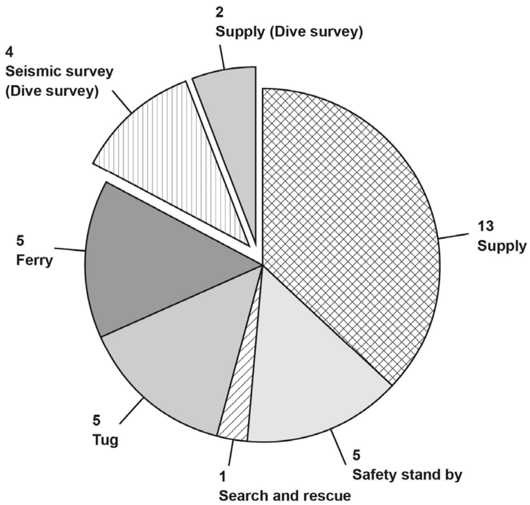

Figure 2. Number and type of vessel sampled during the dry dock and dive surveys.

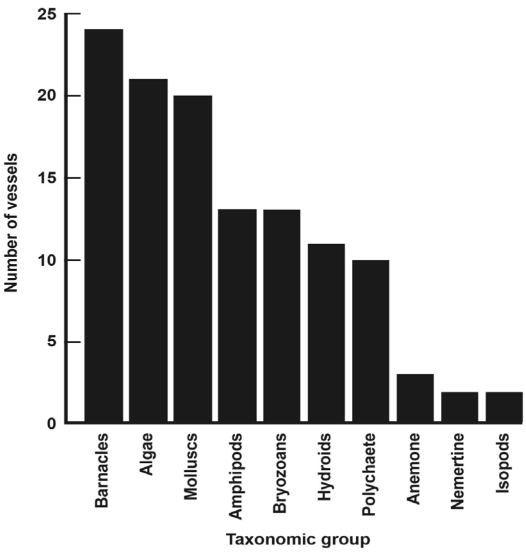

Figure 3. Number of vessels on which each taxon was recorded.

excluded from further analysis (see Table 1). Six vessels were surveyed using the dive team, 3 in Aberdeen Harbour and 3 in Peterhead Harbour (Figure 1 and Table 2). The samples collected by the dive team were of limited value as the poor visibility meant it was difficult to target areas with macro-fouling and the biofilm samples collected did not provide enough material to accurately identify the organisms. The samples were therefore used to provide qualitative information only and were excluded from further analysis.

Vessel type

The type of vessel available to sample in the dry docks was determined by the size and location of the docks. The docks are relatively small and the vessels docking there representative of the vessels trading in the local area i.e. vessels servicing the oil industry and inter-island ferries (Figure 2). The majority of the vessels sampled were supply vessels (13 in dry dock and 2 by dive survey). The dive survey also sampled 4 seismic survey vessels as these tended to be alongside for longer periods of time and were able to accommodate the work of the dive team.

Vessel trade pattern

The vessels sampled in dry dock traded mainly in the North Sea, only five traded to and from the Western Isles on the west coast of Scotland. North Sea vessel routes were typically to and from oil terminals and installations in the northern North Sea, from the docks at Aberdeen and Leith. To our knowledge, no vessels were operating in the southern North Sea. The vessels sampled by the dive team also traded in the North Sea area but some had also traded in international waters prior to their return (Table 2). During their time in the North and Celtic Seas (west coast of Scotland), all vessels were operating in waters of high salinity.

Dry docking intervals

The majority of the vessels sampled had a dry docking interval of between 2.5 and 3 years. Three of the 29 vessels visited were in for repair or refit rather than their usual maintenance and antifoulant replacement. The inter-island ferries are docked once a year and have any work carried out as necessary (Table 1). The work in the dry dock involved washing down the vessel and then applying an undercoat or primer followed by a top coat of the antifoulant paint. The choice of paint was based on suitability for the type of vessel and cost.

Fouling organisms present

Thirty six organisms were identified within ten taxonomic groups recorded (barnacles, amphipods, isopods, molluscs, bryozoans, hydroids, polychaetes, nemertine worms, anemone and algae) from the dry dock samples. Copepods were identified from the dive survey samples only. Some were identified to species level whereas others could not be identified beyond a broad taxonomic group (supplementary material, Table 1S). The presence of algae was noted but no further identification was undertaken. The most commonly found organisms were barnacles, algae and molluscs (Figure 3) which were found on 24, 21 and 20 out of the 24 dry dock vessels sampled respectively. The second most commonly found taxonomic groups were amphipods, bryozoans, hydroids and polychaetes (13, 13, 11 and 10 vessels respectively). Anemones, nemertine worms and isopods were found on a small number of vessels (3, 2 and 2 vessels respectively). One vessel had the three different isopod taxa recorded present and one other vessel had only *Idotea pelagia* Leach, 1815 present.

Although the samples collected by the dive team were excluded from further analysis (see above) the species recorded have been noted in Table 1S. Similar species were found in both dry dock and dive samples but there were three taxa found in the dive survey samples that were not recorded in the dry dock samples. These were harpacticoid and juvenile copepods which may have been present in the harbour water and collected by the divers along with the biofouling sample. A large barnacle species was also collected that may have been *Megabalanus* spp. Hoek, 1913 and could be a species native to warm and tropical seas (Henry and McLaughlin 1986) but as the tergal and scutal plates were missing this could not be confirmed.

Initial attempts were made to assess the abundance of organisms on the vessels but this could not be carried out in a systematic manner. The estimates would therefore not have been representative of the organism abundance and would not have been comparable between vessels. Quantitative information on abundance is therefore not available although photographs of the fouling *in situ* provided qualitative information regarding how established the fouling was.

All species found are common organisms in the North Sea and the waters around Scotland. Of the thirty six species identified, four are known to be non native in this area; the barnacles *Austrominius modestus* (Darwin, 1854) and *Amphibalanus amphitrite* (Darwin, 1854), and the amphipods *Caprella mutica* (Schurin, 1935) and *Jassa marmorata* (Holmes, 1905). *Austrominius modestus* was introduced to Great Britain in 1945 (Eno et al. 1997) and *Amphibalanus amphitrite* is a non native species that is established in European waters and was first recorded in the UK from Shoreham harbour in Sussex in 1937 (Bishop 1950). *Caprella mutica* was first recorded from the west coast of Scotland in 2002 (Willis et al. 2004). There is currently some discussion regarding the status of *Jassa marmorata* in European waters with some taxonomists suggesting it may originate from the NW Atlantic (Conlan 1989; Cohen et al. 2001; Gittenberger 2010). There remains the possibility that additional non-native species were present within the fouling samples as the algae collected was not identified in this study.

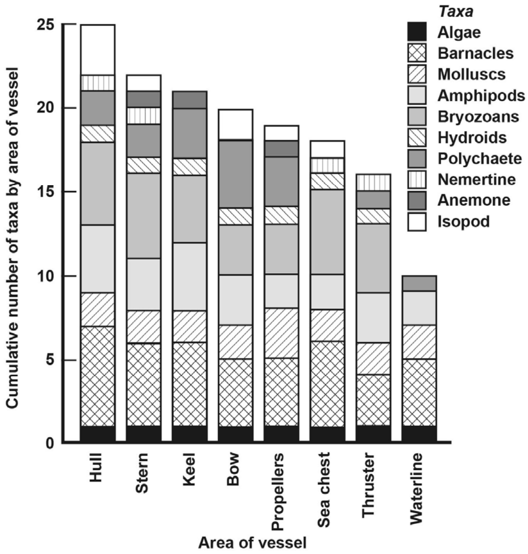

Figure 4. Number of taxa recorded by area of the vessel.

Species present in different areas of the vessel

Samples were recorded as having been taken from one of 8 areas: either from distinct areas with structures such as the keel, thrusters, sea chest, propellers or a distinct line of fouling that indicated the waterline. Other areas included the wider area of the hull i.e. where there were no other structures present, the bow and stern areas were recorded as separate areas of the hull (Table 1 and Figure 4). Not all areas were sampled on all vessels. Algae, barnacles, molluscs and amphipods were present in all areas sampled. Bryozoans and hydroids were present in all areas except the waterline. Polychaetes were not present in samples from the waterline or in the sea chest. Although the taxonomic groups of nemertine worms, anemone and isopods were not found on many vessels they

Table 1. Information regarding dry dock sampling location, vessel type, tonnage either DWT (Dead Weight Tonnage) or Gross Tonnage (in italics), date of last dry dock, main trade route and the area of the vessel sampled (K) Keel, (T) Thruster, (H) Hull, (S) Stern, (SC) Sea Chest, (W) Waterline, (P) Propeller and (B) Bow. Vessel numbers marked with an asterisk (*) had no biofouling and no samples were collected.

Dry Dock	Vessel number (year_vessel number)	Vessel Type	Tonnage DWT or Gross tonnage	Last dry dock (year)	Main trade route	Area of vessel sampled (see key)							
Aberdeen	09_01	Safety standby	1294	3	North Sea	K	T	H	S	SC	W	P	
	09_02	Supply	3184	1st dry dock	East coast of Scotland	K				SC		P	
	09_03	Tug	637	3	Aberdeen	K	T	H	S		W		B
	09_04	Ferry	4719	1	Western Isles of Scotland		T	H	S				
	10_01	Tug	482	3	Sullom Voe, Shetland	K		H	S	SC	W		B
	10_02	Tug	750	2	Sullom Voe, Shetland	K	T	H			W	P	
	10_03	Supply	4100	1st dry dock	North Sea			H	S	SC		P	
	10_04	Tug/Supply	1974	3	North Sea	K	T	H	S			P	B
	10_05	Supply	3075	3	East coast of Scotland	K			S				
	10_06	Safety standby	766	2	East coast of Scotland			H				P	B
	11_01	Supply	2650	3	North Sea		T	H	S		W	P	
	11_04*	Tug	797	2	Sullom Voe, Shetland								
	11_05*	Ferry	324	2	Shetland Islands								
	11_06	Supply	4605	2.5	East coast of Scotland	K	T	H	S				B
	11_07*	Tug	322	2									
	11_10	Supply	3200	Repair	East coast of Scotland		T	H	S				
	11_13	Supply	3302	3	East coast of Scotland	K	T	H		SC		P	
	11_15*	Search and rescue	1800	<1	Western Isles of Scotland								
	11_16	Safety standby	1703	1.5	North Sea	K	T	H	S			P	B
Edinburgh	11_02	Safety standby	804	2	North Sea	K	T		S		W		B
	11_03	Safety standby	909	2.5	North Sea		T	H	S				
	11_08	Supply	1830	3	North Sea	K	T	H	S			P	
	11_09	Supply	3100	2	East coast of Scotland	K	T	H					
	11_11	Supply	1300	3	North Sea			H	S			P	B
	11_12	Supply	850	3	North Sea			H	S				B
	11_14	Supply	3100	3	North Sea	K	T	H				P	
Clyde	11_17	Ferry	4719	2	Western Isles of Scotland	K		H					B
	12_01	Ferry	767	1	Western Isles of Scotland			H	S				
	12_02*	Ferry	666	1	Western Isles of Scotland								

Table 2. Information regarding harbour sampling location, vessel type, Dead Weight Tonnage (DWT), date of last dry dock and main trade route.

Harbour	Vessel number Dive Survey (DS) (year_vessel number)	Vessel Type	Tonnage (DWT)	Last dry dock (years)	Main trade route
Aberdeen	DS10_01	Seismic Survey	876	0.3	Abu Dhabi and North Sea
	DS10_02	Seismic Support	1036	New vessel	Worldwide
	DS10_03	Seismic Survey	1854	1	Cuba, Bermuda, Spain, North Sea
Peterhead	DS10_04	Supply	3573	New vessel	Indian Ocean and North Sea
	DS10_05	Supply	3120	0.2	North Sea
	DS10_06	Seismic Survey		0.6	North Sea

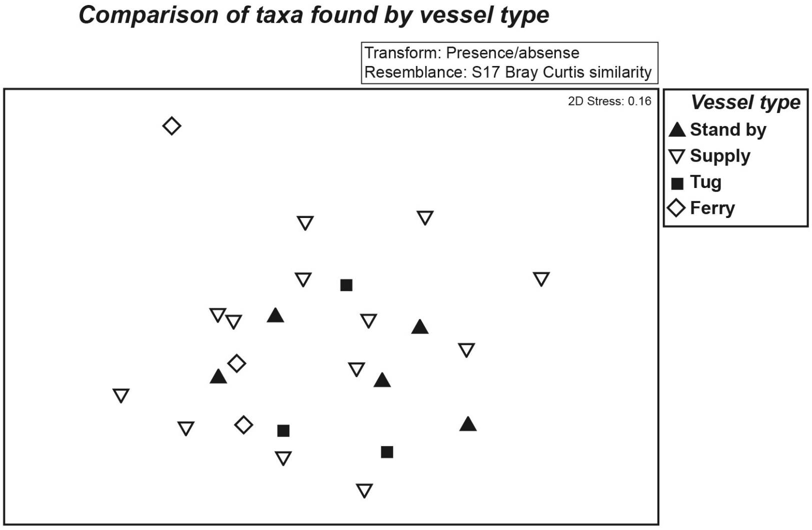

Figure 5. Multi dimensional scaling (MDS) plot of similarity of taxa recorded from each vessel type.

were found in several areas of the vessel when present (Figure 4). For the samples taken during this project the hull, stern and keel had the most species present and the thruster and waterline the least (Figure 4).

To assess the similarity of the species present on the vessels a Multi Dimension Scaling (MDS) plot was produced using PRIMER 6 software (Clarke and Gorley 2006; Clarke and Warwick 2001). The data were transformed to presence/ absence and a Bray-Curtis resemblance applied (Figure 5). The plot illustrates that there were no distinct differences between the species present on the different vessel types and none had a noticeably different composition of species. One ferry seemed to show a different composition of species but sampling on this vessel was only possible in a few areas and very few samples were collected. This is more likely to account for the difference to other vessels. A One Way ANOSIM was also carried out using PRIMER and the Global R statistic of -0.032 confirmed there was no similarity between species assemblage and type of vessel.

Discussion

The study aimed to collect information on the species present and level of biofouling on vessels and use these data in conjunction with information regarding the voyage and maintenance history of the vessel to assess whether certain vessels on certain routes may pose a higher risk of introducing non native species into Scottish waters. Previous studies of biofouled vessels in Scottish waters examined recreational vessels (Ashton et al. 2006a) and although there have been studies of hull biofouling on commercial vessels elsewhere in Europe (Gollasch 2002; Mineur et al. 2008) there have been no such studies in Scottish waters.

The scope of this qualitative study was limited to taking biofouling samples from small coastal vessels that service the North Sea oil industry or operate as inter-island ferries in Scotland. Time and safety considerations meant that the vessels could not be sampled in a consistent manner and the results from each sampling trip are therefore not directly comparable. Larger vessels with international trade routes were targeted using a dive team to sample vessels in two large, busy harbours (Aberdeen and Peterhead) but the method had limited success (see materials and methods) and the samples were subsequently excluded from further detailed analysis. Despite the sampling constraints within the dry docks, this was found to be a far more efficient way of collecting samples, when compared to the dive surveys. Visibility, sampling time, ease of sample collection and fouling coverage estimates were all compromised during the dive surveys. The range of vessel types sampled in dry dock were dominated by tugs, supply and safety standby vessels which provided a good indication of the type of fouling found on vessels that typically trade in Scottish coastal waters.

The majority of the vessels had last been in dry dock within three years and none exceeded this time period. Apart from one vessel that was in for repair all were washed down and had antifoulant either patched or removed and replaced where necessary depending on the condition of the antifoulant already on the vessel. The antifouling on the vessels (as assessed visually) tended to be in good condition and there was only fouling on areas that had damaged paintwork, in niche areas such as around anodes or that were protected from the water flow. There appeared to be no relationship between the last dry docking and fouling burden amongst the vessels surveyed although vessels that were more commonly on the move e.g. ferries appeared less fouled than more regularly stationary vessels e.g. Safety standby vessels. However, no solid conclusions should be drawn from this owing to the limited sample number of 29 vessels and the variation of docking schedules.

The different types of vessel had no differences between the species found (Figure 5) and the vessels had species common to the North Sea present (Table 1S). No new non native species were recorded but established non native species were found, the barnacles *Austrominius modestus* and *Amphibalanus amphitrite* and the skeleton shrimp *Caprella mutica*, all of which have been reported previously as being transported as biofouling on vessels (Eno et al. 1997; Frey et al. 2009). *Caprella mutica* has also been recorded by Ashton et al. (2006b) in seven of ten Scottish marinas surveyed during a rapid assessment exercise. The amphipod *Jassa marmorata* is considered to be native to the NW Atlantic and has spread from there to become a widely distributed species (Conlan 1989; Cohen et al 2001; Gittenberger 2010). Although considered non-native in the eastern Atlantic (Conlan 1989; Cohen et al 2001; Gittenberger 2010; Hines et al. 2000; Pilgrim and Darling 2010; Francis Kerckhof, pers comm) it has also been regarded as a cryptogenic species in this area (Inglis et al. 2006). Confusion surrounding morphological identification of the species with others in the *Jassa* genus is most likely a factor in this debate. As discussed by Gittenberger (2010) identification issues are likely to have confused records of this species in European waters as it is easily confused with the native *J. herdmani* (Walker, 1839) and *J. falcata* (Montagu, 1808). A redescription of the genus by Conlan (1989) found many of the previously described *J. falcata* specimens were in fact a mix of various *Jassa* species. *J. marmorata* is a highly successful coloniser on artificial substrates such as buoys, pilings, harbour structures and vessel hulls and can become the most abundant amphipod on such structures, dominating fouling communities (Beermann and Franke 2012). It was the most frequently observed non native species in this study.

Although results from the dive surveys were not included in any data analyses, it is worth highlighting possible *Megabalanus* spp. specimens that were found during these surveys. The specimens could not be identified to species level with accuracy as the tergal and scutal plates were missing. This genus would generally be found in warm and tropical seas (Henry and McLaughlin 1986) although some species are known to have become established outside their native range e.g. *M. coccopoma* (Darwin, 1854), *M. tintinnabulum* (Linnaeus, 1758) and *M. rosa* (Choi, Anderson and Kim, 1992) (Kerckhof and Cattrijsse 2001; Kerckhof 2002; Kerckhof et al. 2010; Newman and McConnaughey 1987; Yamaguchi et al. 2009). The specimens from this study were found on a vessel that had been trading in the Indian Ocean for a 6 month period, before returning to the North Sea for 5 months prior to dry docking. Although it is likely that none survived the journey back to Scotland as no live specimens were noted in the video footage taken by the divers or in the samples they collected, it is probable that these specimens represent a species of barnacle not currently recorded from UK waters. However *M. coccopoma* and *M. tintinnabulum* are not unknown from the southern North Sea and were first recorded in Belgian waters in the late 1990s (Kerckhof and Cattrijsse 2001). This highlights the potential these species have in expanding their range and adapting to cooler climates.

A larger study carried out in Europe by Gollasch (2002) collected 131 hull fouling samples from vessels and recorded species that were non native (both established and non established) to European waters and found that nearly all (96.2%) contained at least one non native species. The non native species found in this study were not present in such a number of samples, of the 24 vessels from which samples were taken during dry dock surveys, *Jassa marmorata* was found on eight vessels, *Austrominius modestus* on three, *Caprella mutica* on two, and *Amphibalanus amphitrite* on one (*A. amphitrite* was additionally present on a dive survey vessel) One reason for this difference could be owing to factors such as the smaller number of vessels sampled, and the trade pattern and maintenance of the vessels. The vessels sampled during this study generally spent their time operating between ports such as Aberdeen and Peterhead and the oil fields of the North Sea i.e. they were not calling at several different ports within Europe or around the world as were the vessels sampled by Gollasch (2002).

Another factor that may account for the differences between the number of vessels with non native species present in this study and those sampled by Gollasch (2002) is that for some species found in this study e.g. *A. amphitrite,* southern England may represent its northern most distribution even though it is a widely distributed species and tolerant of wide temperature and salinity ranges (Bishop 1950). It is known to be established in the southern North Sea (Kerckhof and Cattrijsee 2001; Kerckhof et al. 2007) but individuals have been observed as far north as Shetland (Eno et al. 1997) although it was not known if these were part of a breeding population. It has also previously been reported that conditions in the German Bight are unfavorable for successful larval recruitment, with water temperatures being too low (Wiegemann 2008). However, the fact that live specimens of *A. amphitrite* were collected during this study illustrates its ability to withstand a wide temperature range. One vessel from which they were collected (dry dock survey) had spent time in Turkish waters before returning to the North Sea for four months prior to dry docking. A second vessel (dive survey) had spent six months in the Indian Ocean prior to arriving in the dry dock five months later. It is not known if the specimens became established as biofouling in these warmer waters and survived the journey back to the North Sea or if they had become established here. It is possible that *A. amphitrite* is capable of tolerating lower temperatures than previously thought.

Of the other species found in this study, *Austrominius modestus* was first recorded in UK waters in 1945 having arrived from southern Australia and New Zealand (Bishop 1947). It is a very successful invader throughout the British Isles with reports of outcompeting and replacing local species in southwest Scotland (Barnes and Barnes 1961) but also of negligible effects on local barnacle populations in other areas such as Lough Hyne in southwest Ireland (Watson et al. 2005). Watson et al. (2005) also note how the barnacle prefers to establish in more sheltered areas and the presence of individuals from within sea chest and keel areas in this study supports this observation. Presence in the bow area from one vessel suggests that it may, on occasion, be able to tolerate more exposed surfaces.

The first record of *Caprella mutica* in British waters was from Lynne of Lorne near Oban, in 2000 (Willis et al. 2004). Originally from northeast Asia, it has expanded its range within the UK and Europe and has been observed in around 37 locations within Scotland (Cook et al. 2007; Schuckel et al. 2010). *C. mutica* is tolerant of a wide range of temperatures and salinities (Ashton et al. 2007) and is usually associated with artificial structures present at aquaculture sites, harbours and marinas (Beerman and Franke 2011; Willis et al. 2004). In this study, *C. mutica* specimens were part of the fouling communities within the sea chest and keel areas of two vessels. One of these vessels does not work beyond the Aberdeen area and movements of the second vessel are normally between Aberdeen and Peterhead. Although previously identified from Peterhead, Aberdeen appears to be a new location not listed by Cook et al. (2007). Keel and hull areas appear to be common areas for *C. mutica* to appear within the biofouling communities on vessels, especially when those communities consist of macroalgae (Cook et al. 2007) while its presence within sea chests does not appear to be documented for vessels in Scottish waters. Coutts et al. (2003) report an unidentified *Caprella* specimen from the sea chest of a passenger ferry during a study in New Zealand and highlight these structures as a serious introduction threat. In this study, areas of the keel associated with *C. mutica* were indeed associated with macroalgae and other biofouling organisms including barnacles, mussels and amphipods. Concerning the sea chest, a greater range of organisms was present, including barnacles, mussels, amphipods, bryozoans and polychaetes. It seems likely that this well protected area is favourable to *C. mutica*, providing a safe habitat from predators and the actions of waves and currents. *C. mutica* was the only non-native species found during this study that has also been observed within the fouling communities on leisure craft in Scotland (Ashton et al. 2006a and b). It is possible that this species is more likely to spread to new locations throughout Scotland than the other three species if it is utilising both recreational and commercial vessels as vectors.

Comparisons with previous studies of biofouling on commercial vessels will have to take into account that these have been both qualitative (Gollasch 2002) and quantitative (Davidson et al.

2009; Sylvester and MacIsaac 2010; Sylvester et al. 2011). As with our study barnacles and molluscs were the most commonly sampled fouling species found by Gollasch (2002). The most common species noted by Gollasch (2002) was *Balanus improvisus* (now *Amphibalanus improvisus* (Darwin, 1854)), which was not recorded in the present study. *B. improvisus* is a common species worldwide and inhabits oceanic and brackish waters, in shallow and tidal areas (Foster 1987). It is known to be tolerant of wide temperature and salinity ranges with even its larval stages demonstrating a huge tolerance to simulated warming and ocean acidification (Pansch et al. 2012). Its distribution in UK waters is thought to be most common on the northwest and southwest coasts in England and Wales, mainly around large estuaries, with a limited distribution on the English northeast coast and Scotland (Sweet 2011) which may account for its absence in this study. *B. improvisus* and *B. crenatus* Bruguière, 1789 (which was found in this study) could also be confused with one another as they are very similar (see e.g. Hayward and Ryland 1995) but several of the specimens were sent to taxonomic experts for confirmation of identification and it is unlikely that this has been the case.

Other studies on commercial vessels carried out by video (Coutts and Taylor 2004; Davidson et al. 2009) categorised taxa into broad groups but were not able to identify individual species. Coutts and Taylor (2004) concluded that biofouling was greatest in dry docking support strips and sea-chest gratings. Our study did find some areas such as dry docking support strips to be more fouled than the surrounding area on some vessels but there were also areas of paint damage or protected niche areas e.g. in a moon pool (an opening from the deck through to the bottom of vessel hull to allow dive survey equipment to be lowered safely) that were fouled more than the surrounding area on certain vessels. As each vessel was different in design and the areas sampled was dictated by work being carried out in the dry dock it was not possible to compare the fouled areas across the different vessels. Our study also had to allow for the fact that although the vessel was in dry dock it was not always possible to view the fouling over the whole vessel as cleaning would generally start immediately the dock was drained of water. Davidson et al. (2009) also found that dry docking support strips of container vessels were not as fouled as described by Coutts and Taylor (2004) and that the accumulation of fouling on containerships may be lower than on other vessel types. However, as with this current study, a relatively small number of vessels (twenty two) were sampled by Davidson et al. (2009) and the authors caution that further data is required to gain a better understanding of the differences in fouling on different vessel types.

In an attempt to tackle the problems mentioned above with the data collected in relation to hull samples Sylvester and MacIsaac (2010) and Sylvester et al. (2011) sampled 40 vessels in Great Lakes' ports using both video recording and collecting scrape samples. These results were then used to develop a simple model to assess the risk of introducing non native species *via* biofouling. However, in contrast to our study, the vessels sampled by Sylvester et al. (2011) had ports of call throughout the world which allowed a model to be developed to calculate the risk of introducing non native species. Our study provides qualitative data that could be used to provide information regarding the species present on vessels that service the oil industry in the North Sea but could not be used to provide an overall assessment of the risk of introducing non native species into UK waters. In order to carry out such an assessment a greater variety of vessels would have to be sampled and, as dry docks in the UK are relatively small, other methods would have to be employed to collect samples from larger, ocean going vessels.

This study provides qualitative data regarding which species are present on vessels typical of those trading in the North Sea. The species found are common to the North Sea area and also include a number of established non native species. No new non native species were found although dead specimens that were possibly *Megabalanus* spp. were observed on one vessel during dive surveys. The vessels were maintained on a regular schedule and the anti-fouling paint was generally in good condition. There were areas of damage to the paintwork in some cases e.g. if the vessel tended to always come alongside the berth on one side then there would be more paint damage on that side of the vessel. As with other studies it was the protected niche area or those areas protected from the flow of water that tended to be fouled although it was not possible to compare the level of fouling in these areas between the vessels. In order to develop a model such as that developed by Sylvester et al. (2011) for Scottish waters more data would be required to be collected on a wider variety of vessels than was possible in this study.

Acknowledgements

This work was funded by the Scottish Government under ROAME ST0030. The authors would like to thank staff at Dales Marine Services Ltd (Aberdeen and Leith) and Garvel Clyde (Greenock) for their cooperation and assistance during sampling. Thanks also to Francis Kerckhof (Royal Belgian Institute of Natural Sciences), John Bishop (Plymouth Marine Laboratory), Liz Cook and Chris Beveridge (Scottish Association for Marine Science), Claire Scanlon and Sarah Mason (Scottish Environment Protection Agency) and colleagues at Marine Scotland Science for their advice and assistance with the species identifications. Thanks also go to the Marine Scotland Science Dive Team for their assistance and efforts during the dive surveys. Finally, the authors would like to thank two reviewers for their useful comments and time taken to review and improve this manuscript.

References

Ashton G, Boos K, Shucksmith R Cook EJ (2006a) Risk assessment of hull fouling as a vector for marine non natives in Scotland. *Aquatic Invasions* 1: 214–218, http://dx.doi.org/10.3391/ai.2006.1.4.4

Ashton G, Boos K, Shucksmith R, Cook EJ (2006b) Rapid assessment of the distribution of marine non natives species in marinas in Scotland. *Aquatic Invasions* 1: 209–213, http://dx.doi.org/10.3391/ai.2006.1.4.3

Ashton GV, Willis KJ, Burrows MT, Cook EJ (2007) Environmental tolerance of *Caprella mutica*: Implications for its distribution as a marine non-native species. *Marine Environmental Research* 64: 305–312, http://dx.doi.org/10.1016/j.marenvres.2007.02.003

Barnes H, Barnes M (1961) Recent spread and present distribution of the barnacle *Elminius modestus* Darwin in South-West Scotland. *The Glasgow Naturalist* 18: 121–129

Beerman J, Franke H-D (2011) A supplement to the amphipod (Crustacea) species inventory of Helgoland (German Bight, North Sea): indication of rapid recent change. *Marine Biodiveristy Records* 41(e41): 1–15

Beermann J, Franke H-D (2012) Differences in resource utilization and behaviour between coexisting *Jassa* species (Crustacea, Amphipoda). *Marine Biology* 159: 951–957, http://dx.doi.org/10.1007/s00227-011-1872-7

Bishop MWH (1947) Establishment of an immigrant barnacle in British coastal waters. *Nature 159*: 501–502, http://dx.doi.org/10.1038/159501a0

Bishop MWH (1950) Distribution of *Balanus amphitrite* Darwin var. *denticulata* (Broch). *Nature* 165: 409–410, http://dx.doi.org/10.1038/165409a0

Carlton JT (1985) Transoceanic and interoceanic dispersal of coastal marine organisms: The biology of ballast water. *Oceanography and Marine Biology. An Annual Review* 23: 313–371

Chambers SJ, Muir AI (1997) Polychaetes: British Chrysopetaloidea, Pisionoidea and Aphroditoidea. Synopses of the British Fauna No. 54. Linnean Society of London, Academic Press, 202 pp

Clarke KR, Gorley RN (2006) PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation. 2nd Edition. PRIMER-E, Plymouth

Cohen AN, Berry HD, Mills CE, Milne D, Britton-Simmons K, Wonham MJ, Secord DL, Barkas JA, Bingham B, Bookheim BE, Byers JE, Chapman JW, Cordell JR, Dumbauld B, Fukuyama A, Harris LH, Kohn AJ, Li K, Mumford Jr, TF, Radashevsky V, Sewell AT, Welch K (2001) Washington State Exotics Expedition 2000: A rapid survey of exotic species in the shallow waters of Elliott Bay, Totten and Eld Inlets, and Willapa Bay. Washington State Department of Natural Resources, Olympia, 46 pp

Conlan K (1989) Revision of the crustacean amphipod genus Jassa Leach (Corophioidea: Ischyroceridae). *Canadian Journal of Zoology* 68: 2031–2075, http://dx.doi.org/10.1139/z90-288

Cook EJ, Jahnke M, Kerckhof F, Minchin D, Faase M, Boos K, Ashton G (2007) European expansion of the introduced amphipod *Caprella mutica* Schurin 1935. *Aquatic Invasions* 2: 411–421, http://dx.doi.org/10.3391/ai.2007.2.4.11

Coutts ADM, Moore KM, Hewitt CL (2003) Ships' seachests: an overlooked transfer mechanism for nonindigenous marine species? *Marine Pollution Bulletin* 46: 1504–1515, http://dx.doi.org/10.1016/S0025-326X(03)00292-3

Coutts ADM, Piola RF, Hewitt CL, Connell SD, Gardner JPA (2010) Effect of vessel voyage speed on survival on biofouling organisms: implications for translocation of non-indigenous marine species. *Biofouling* 26: 1–13, http://dx.doi.org/10.1080/08927010903174599

Coutts ADM, Taylor MD (2004) A preliminary investigation of biosecurity risks associated with biofouling on merchant vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 38: 215–229, http://dx.doi.org/10.1080/00288330.2004.9517232

Davidson IC, Brown CW, Sytsma MD, Ruiz GM (2009) The role of containerships as transfer mechanisms of marine biofouling species. *Biofouling* 25: 645–655, http://dx.doi.org/10.1080/08927010903046268

Davidson IC, McCann LD, Fofonoff PW, Sytsma MD, Ruiz GM (2008) The potential for hull-mediated species transfers by obsolete ships on their final voyages. *Diversity and Distributions* 14: 518–529, http://dx.doi.org/10.1111/j.1472-4642.2008.00465.x

Drake JM, Lodge DM (2007) Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. *Aquatic Invasions* 2: 121–131, http://dx.doi.org/10.3391/ai.2007.2.2.7

Eno NC, Clark RA, Sanderson WG (eds) (1997) Non native marine species in British waters: a review and directory. Joint Nature Conservation Committee, Peterborough, 136 pp

Floerl O, Inglis GJ (2003) Boat harbour design can exacerbate hull fouling. *Austral Ecology* 28: 116–127, http://dx.doi.org/10.1046/j.1442-9993.2003.01254.x

Floerl O, Inglis GJ (2005) Starting the invasion pathway: the interaction between source populations and human transport vectors. *Biological Invasions* 7: 589–606, http://dx.doi.org/10.1007/s10530-004-0952-8

Floerl O, Inglis GJ, Hayden BJ (2005) A risk-based predictive tool to prevent accidental introductions of non-indigenous marine species. *Environmental Management* 35: 765–778, http://dx.doi.org/10.1007/s00267-004-0193-8

Foster BA (1987) Barnacle ecology and adaptation. Crustacean issues 5: Barnacle biology, pp 113–133

Frey M, Gartner HN, Murray CC, Therriault TW (2009) First confirmed records of the non-native amphipod *Caprella mutica* (Schurin 1935) along the coast of British Columbia, Canada, and the potential for secondary spread via hull fouling. *Aquatic Invasions* 4: 495–499, http://dx.doi.org/10.3391/ai.2009.4.3.10

Gittenberger A, Rensing M, Stegenga H, Hoeksema B (2010) Native and non-native species of hard substrata in the Dutch Wadden Sea. *Nederlandse Faunistische Mededelingen* 33: 21–75

Gollasch S (2002) The importance of ship hull fouling as a vector of species introductions into the North Sea. *Biofouling* 18: 105–121, http://dx.doi.org/10.1080/08927010290011361

Hayward PJ, Ryland JS (1995) Handbook of the marine fauna of North-West Europe. Oxford University Press, 800 pp

Henry DP, McLaughlin PA (1986) The recent species of Megabalanus (*Cirripedia: Balanomorpha*) with special emphasis on *Balanus tintinnabulum* (*Linneaus)* sensu lato. *Zoologische Verhandelingen* 235: 1–69

Hewitt CL, Martin RB (1996) Port Surveys for Introduced Marine Species – Background Considerations and Sampling Protocols. Centre for Research on Introduced Marine Pests. Technical Report No. 4. CSIRO Marine Research, Hobart, 40 pp

Hewitt CL, Martin RB (2001) Revised protocols for baseline port surveys for introduced marine species: survey design, sampling protocols and specimen handling. Centre for Research on Introduced Marine Pests. Technical Report No. 22. CSIRO Marine Research, Hobart, 46 pp

Hines AH, Ruiz GM, Fofonoff PW (2000) Summary of NIS in Prince William Sound and Alaska. In: Hines AH, Ruiz GM (eds), Biological Invasions of Cold-Water Coastal Ecosystems: Ballast-Mediated Introductions in Port Valdez/ Prince William Sound, Alaska. Final Project Report, 26 pp

Inglis G, Gust N, Fitridge I, Floerl O, Woods C, Hayden B, Fenwick G (2006) Dunedin Harbour (Port Otago and Port Chalmers). Base line survey for non-indigenous marine species (Research Project ZBS2000/4). Biosecurity New Zealand Technical Paper No: 2005/10, 104 pp, http://www.maf.govt.nz/publications

International Maritime Organization (2005) Ballast Water Management Convention. International Maritime Organization, London, 138 pp

Kerckhof F (2002) Barnacles (Cirripedia, Balanomorpha) in Belgian waters, an overview of the species and recent evolutions, with emphasis on exotic species. *Bulletin Van Het Koninklijk Belgisch Instituut Voor Natuurwetenschappen* 72: 93–104

Kerckhof F, Cattrijsee A (2001) Exotic Cirripedia (Balanomorpha) from Buoys off the Belgian Coast. *Senckenbergiana maritime* 31 (2): 245–254

Kerckhof F, Haelters J, Gollasch S (2007) Alien species in the marine and brakish ecosystem: the situation in Belgian waters. *Aquatic Invasions* 2: 243–257, http://dx.doi.org/10.3391/ai.2007.2.3.9

Kerckhof F, Haelters J, Degraer S (2010) The barnacles *Chirona* (*Striatobalanus*) *amaryllis* (Darwin 1854) and *Megabalanus coccopoma* (Darwin 1854) (Crustacea, Cirripedia): two invasive species new to tropical West African waters. *African Journal of Marine Science* 32(2): 265–268, http://dx.doi.org/10.2989/1814232X.2010.501573

Lincoln RJ (1979) British marine amphipoda: Gammaridea. British Museum (Natural History), 658 pp

Marine Environment Protection Committee (MEPC) (2011) Guidelines for the control and management of ships' biofouling to minimize the transfer of aquatic species. Resolution MEPC.207 (62). MEPC 62/24/Add.1 Annex 26

Mineur F, Johnson MP, Maggs CA (2008) Macroalgal introductions by hull fouling on recreational vessels: Seaweeds and sailors. *Environmental Management* 42: 667–676, http://dx.doi.org/10.1007/s00267-008-9185-4

Newman WA, McConnaughey RR (1987) A tropical eastern Pacific barnacle, *Megabalanus coccopoma* (Darwin), in southern California, following El Niño 1982-83. *Pacific Science* 41(1–4): 31–36

Pansch C, Nasrolahi A, Appelhans YS, Wahl M (2012) Impacts of ocean warming and acidification on the larval development of the barnacle *Amphibalanus improvisus. Journal of Experimental Marine Biology and Ecology* 420–421: 48–55, http://dx.doi.org/10.1016/j.jembe.2012.03.023

Pilgrim EM, Darling JA (2010) Genetic diversity in two introduced biofouling amphipods (*Ampithoe valida* & *Jassa marmorata*) along the Pacific North American coast: investigation into molecular identification and cryptic diversity. *Diveristy and Distributions* 16(5): 827–839, http://dx.doi.org/10.1111/j.1472-4642.2010.00681.x

Schuckel U, Schuckel S, Beck M, Liebazeit G (2010) New range expansion of *Caprella mutica* Schurin, 1935 (Malacostraca: Caprellidae) to the German coast, North Sea. *Aquatic Invasions* 5 (Suppl. 1): S85–S89, http://dx.doi.org/10.3391/ai.2010.5.S1.018

Sweet N (2011) Acorn barnacle: *Balanus improvisus*. GB Non Native Species Secretariat. https://secure.fera.defra.gov.uk/nonnativespecies/factsheet/factsheet.cfm?speciesId=456 (Accessed 10 December 2013)

Sylvester F, Kalaci O, Leung B, Lacoursière-Roussel A, Murray CC, Choi FM, Bravo MA, Therriault TW, MacIsaac HJ (2011) Hull fouling as an invasion vector: can simple models explain a complex problem? *Journal of Applied Ecology* 48: 415–423, http://dx.doi.org/10.1111/j.1365-2664.2011.01957.x

Sylvester F, MacIsaac HJ (2010) Is vessel hull fouling an invasion threat to the Great Lakes? *Diversity and Distributions* 16: 132–143, http://dx.doi.org/10.1111/j.1472-4642.2009.00622.x

Watson DI, O'Riordan RM, Barnes DKA, Cross T (2005) Temporal and spatial variability in the recruitment of barnacles and the local dominance of *Elminius modestus* Darwin in SW Ireland. *Estuarine Coastal and Shelf Science* 63: 119–131, http://dx.doi.org/10.1016/j.ecss.2004.10.015

Wiegemann M (2008) Wild cyprids metamorphosing in vitro reveal the presence of *Balanus amphitrite* Darwin, 1854 in the German Bight basin. *Aquatic Invasions* 3: 235–238, http://dx.doi.org/10.3391/ai.2008.3.2.14

Willis KJ, Cook EJ, Lozano-Fernandez M, Takeuchi I (2004) First record of the alien caprellid amphipod, *Caprella mutica*, for the UK. *Journal of the Marine Biological Association of the UK* 84: 1027–1028, http://dx.doi.org/10.1017/S0025315404010355h

Yamaguchi T, Prabowo RE, Ohshiro Y, Shimono T, Jones D, Kawai H, Otani M, Oshino A, Inagawa S, Akaya T, Tamura I (2009) The introduction to Japan of the Titan barnacle, *Megabalanus coccopoma* (Darwin 1854) (Cirripedia: Balanomorpha), and the role of shipping in its translocation. *Biofouling* 25: 235–333, http://dx.doi.org/10.1080/08927010902738048

Supplementary material

The following supplementary material is available for this article:

Table 1S. Taxa found on each vessel sampled in dry dock.

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2014/Supplements/MBI_2014_McCollin_Brown_Supplement.xls