Biol Invasions (2010) 12:2573–2583
DOI 10.1007/s10530-009-9666-2

ORIGINAL PAPER

Semi-submersible rigs: a vector transporting entire marine communities around the world

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Received: 6 June 2008 / Accepted: 16 November 2009 / Published online: 29 November 2009

Abstract A virtually intact subtropical reef community (14 phyla, 40 families and 62 non-native taxa) was associated with a rig under tow from Brazil that became stranded on the remote island of Tristan da Cunha. This exposes rigs as a significant vector spreading alien marine organisms, and includes the first records of free-swimming marine finfish populations becoming established after unintentional movement. With relatively trivial effort, a pre-tow clean would have obviated the need to salvage and dispose of the rig (undertaken largely to address concerns about invasive species), at a cost of ~US$20 million. Our findings show that towing biofouled structures across biogeographic boundaries present unexcelled opportunities for invasion to a wide diversity of marine species. Better control and management of this vector is required urgently. Simultaneous, unintentional introductions of viable populations of multiple marine organisms are rare events, and we develop a basic framework for rapid assessment of invasion risks.

Keywords Invasive alien marine species · Marine environmental management · Oil rigs · Risk assessment

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Introduction

Invasive species have devastating biodiversity and economic impacts (Mack et al. 2000; Pimental 2002; Thresher and Kuris 2004). The increase in volume and speed of transoceanic travel from the 19th century to the present has seen a concurrent rise in the introduction of alien marine species (Carlton 1987; Cohen and Carlton 1998; Everett 2000; Mack et al. 2000; Bax et al. 2003). This increase in prevalence of invasions of the near shore environment in recent years has stimulated several global initiatives to address the issues (Mooney 1999; Everett 2000; Bax et al. 2003; de Costa Fernandes et al. 2003). The impacts of many invasive species (marine and other) remain unknown, and the predictability of their direct and indirect effects remains uncertain (Hobbs 1989; Peterson and Vieglais 2001; Hayes and Barry 2007; Wanless et al. 2007). Nonetheless, based upon the documented extent of species invasions and the scope of their effects, it is imperative that risk assessments are undertaken where incidents pose an environmental and economic risk through the possible introduction of non-native species (Bax et al. 2001; Hayes 2002a, b; Hutchings et al. 2002; Drake and Lodge 2006; Herborg et al. 2007). These should assess the likelihood of potential invasions and, where applicable, examine ways of removing or reducing that risk to acceptable levels (Bax et al. 2003).

The Tristan da Cunha archipelago comprises four major islands: the main island of Tristan da Cunha, hereafter 'Tristan', two satellite islands Nightingale and Inaccessible *ca* 20 nm distant from it, and Gough Island, some 350 nm to the SSE. These islands are extremely remote (>1,500 nm from Africa, the nearest continental landmass) and, being volcanic in origin, are truly oceanic. Oceanic islands are characterised by 'disharmonic' communities in which vacant niches occur due to the low probabilities of many taxa dispersing and colonising such remote, oceanic locations (Sadler 1999). Island faunal and floral communities are also characterised by high levels of endemism, and the vulnerability of these communities to invasive species is high, with terrestrial extinctions on islands typically outnumbering continental extinctions by an order of magnitude (Diamond 1989; Pimm et al. 1993; Steadman 1995; Purvis et al. 2000; Simberloff 2000; Simberloff 2001; Simberloff 2003; Blackburn et al. 2004; Duncan and Blackburn 2007). Marine environments around isolated islands are typically also depauperate but high in endemism, and this has been mooted as increasing their vulnerability to biological invasions (Hutchings et al. 2002). At Tristan, diving and shore surveys have recorded very low diversity in many animal groups, although the algae are quite speciose (Scott and Andrew 2007). The impact of alien species is the single biggest threat to the biota of the Tristan da Cunha archipelago (Jones et al. 2002; BirdLife International 2004; Wanless et al. 2007).

The Tristan economy is sustained principally by a well-managed inshore fishery for the Tristan rock lobster *Jasus tristani* (Angel and Cooper 2006). Subsistence fishing is also a significant contributor to the household economies of Tristan residents. If environmental changes are wrought by, for example, the establishment of marine invasive alien species that lead to a decrease in the stock or sustainable yield of edible finfish or lobsters, the Tristan economy would suffer immediate and direct consequences (Bax et al. 2003).

On 5 March 2006, the tug *Mighty Deliverer* departed from Macae, Brazil for Singapore, towing the decommissioned, semi-submersible petrochemical production platform (hereafter referred to in the generic 'rig') *A Turtle* (ex *Petrobras XXI*). The tug encountered difficulties in the South Atlantic and released the tow on 30 April. The rig was discovered aground at Tristan by island inhabitants on 7 June 2006. It was lying on the south east coast of the island at Trypot Bay (37° 08.788′ S, 12° 14.651′ W). An initial inspection of the stranded rig showed it to be heavily fouled with species alien to Tristan (Scott 2006). Here we report a comprehensive inventory of the alien marine fauna associated with the rig, as well as results of surveys of surrounding sub-tidal and intertidal areas for possible spread of living alien organisms away from the rig.

Due to the rarity of multiple, simultaneous marine introductions, we developed a basic framework for assessing rapidly the risk that each organism poses, with preliminary results for certain species. Risks posed by alien species include competition, predation and invasion of vacant niches, any of which could precipitate changes in community structure or composition, or ecosystem functioning. Another concern (not assessed) is that alien species may harbour parasites or pathogens against which the native fauna have little or no immunity. Thus the arrival on Tristan of the rig and its associated fauna poses potentially significant threats to the Tristan environment. There is a strong economic imperative to understanding the nature and predicting the potential consequences of any alien species becoming established in Tristan waters, and we recommend monitoring the possible survival and colonisation of species from the rig and a regular check of lobsters and fish from the stranding site for parasites and pathogens. While fouling of rigs is an acknowledged vector for marine invasive alien species (Bax et al. 2003), this study represents the first practical assessment of the magnitude of the potential risks of rigs as vectors of marine invasive species, and is a sobering lesson with much general applicability.

Methods

Marine alien species

Two underwater surveys of the rig were conducted, from 21 September to 4 October 2006 (6 dives) and from 24 December 2006 to 22 January 2007 (26 dives). Pairs of divers collected specimens by hand in plastic bags, and used scrapers and hammers to dislodge colonies of coral, barnacles, bivalves and other large encrustations, which were later broken open for examination of infauna.

The initial rig survey was qualitative, to establish the current state of biota on the rig, in order to inform subsequent actions. Divers concentrated on obtaining collections of macroscopic species present for subsequent identification, and a photographic record of the biota on different parts of the rig. Poor diving conditions prevented any attempt at quantitative sampling during this survey.

During the second survey, coral chunks and other fouling organisms were collected from ten plots, each 20×20 cm, situated on the exterior of the rig. Plots were taken at random from various positions on the rig, ensuring that variation in water depth was also accounted for. Fish were collected using the piscicide rotenone and spearguns. Three 40 cm-long traps with either 3 or 20 mm mesh size were deployed against the sides of horizontal and vertical structures of the rig. Traps were baited with the native five-finger fish (*Acantholatris monodactylus*) and deployed over 3 days to collect small fish species and crustaceans. During all dives we searched for alien species and any new species were collected wherever possible.

Systematic searches were also performed on natural reefs up to approximately 50 m away from the rig. Any species that were thought to originate from the rig were collected or photographed for later identification. Additional control sites were surveyed away from the immediate vicinity of the rig and entailed visual searches by three divers for at least 10 min at approximate depths of 5, 10 and 20 m. Searches were performed along transect lines laid perpendicular to the bathymetric contours, and GPS positions recorded for future monitoring. Transects were in line with the rig, 500 and 1,000 m on either side of the rig, totalling five transect lines and 15 sites. On 31 October and 23 November 2007 (after the removal of the rig) we did an additional six monitoring dives at the rig site and nearby.

Samples of Tristan rock lobster were collected from the rig and from a remote site during the 2006/07 survey. These samples, together with all the alien species collected from the rig will be deposited in the collection facility of the South African Institute for Aquatic Biodiversity in Grahamstown, South Africa for a minimum of 10 years, and will be made available for future analysis as required.

Risk Assessment

This assessment is predicated on the assumption that the native or alien status of a species can be reliably determined. An invasive alien species is defined (according to the Global Invasive Species Programme) as one “that causes, or has the potential to cause, harm to the environment, economies, or human health” (GISP 2005). There are numerous approaches for assessing the invasion risk that alien marine species pose (e.g. Hayes 2002a, b; Lewis et al. 2006). For a review, see Hewitt and Hayes (2002). We used a simplified fault-tree type risk analysis (Fig. 1) (Hayes 2002b) and a four-level hierarchical assessment of risk to the Tristan environment, based on four stages of invasion, namely arrival (1), persistence (2), spread (3) and becoming invasive (4) (Hayes 2002b; Williamson 2006). The assessment accounted for the fact that the substrate on which many of the alien species depend/reside, i.e. the rig, was removed. The hierarchy moves from low/zero survival on the rig (negligible risk) to becoming an invasive alien species (highest risk).

For invasion stage 1, species were either dead, apparently moribund or had decreased in abundance over time. Species at invasion stage 2 were surviving on the rig but showed no sign of spreading off the rig or of reproducing. For species assessed at invasion stages

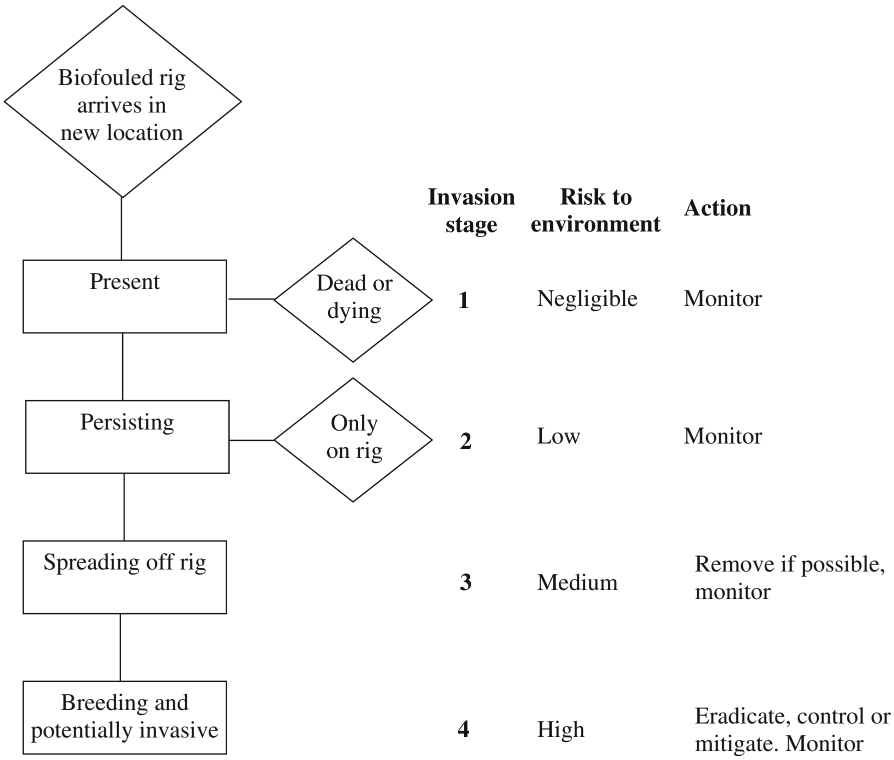

Fig. 1 Fault-tree risk analysis of alien marine species becoming invasive in the Tristan environment following the stranding of a heavily bio-fouled semi-submersible rig in June 2006

2–4, i.e. where risk was not negligible, we considered the biology/ecology of the species for further risk assessment. For example, because the rig was ultimately removed species that are sessile or have very low dispersal ability posed less risk than species that are mobile and may move away from the rig.

Terrestrial alien species

We searched for signs of rodents, insects and other potentially invasive alien species on the rig. The most obvious location for any rodent signs was the kitchen area, but dormitories were searched and a general inspection of the entire rig was performed.

Results

Marine alien species

The initial survey found the submerged parts of the rig to be heavily colonised by coral, barnacles and bivalves, with other organisms living on and within the hard biota (Table 1). Nearly all the colonies of the main coral species *Tubastraea coccinea* were dead, but their persistent hard calcareous skeletons provided a sheltered micro-habitat for numerous boring bivalves, polychaete worms, small crabs, amphipods and other crustaceans. Many of the large acorn barnacles (*Megabalanus tintinnabulum*) were alive and feeding, while dead barnacle shells were inhabited by small crabs, other small invertebrates and the variable blenny *Parablennius pilicornis* (Blenniidae). Small sponges, hydroids and bryozoans frequently colonised both inside and outside surfaces of barnacle shells. The brown mussel *Perna perna* was present as scattered live individuals in several location on the rig, and, from evidence of numerous persisting byssus threads, had previously formed a dense zone around 1–2 m deep on the upper parts of the rig legs. Anemones *Bunodosoma caissarum* and *Anemonia melanaster*, the whelk *Thais haemastoma*, several species of urchin and a variety other animal species were seen on this first survey. Several unidentified

Table 1 The alien species collected on or around the rig

Group	Species	Alien or native	Reference	Assessed risk level
Diatoms		Unknown		1
Algae		Unknown		1
Porifera (sponges)				
Two Species	Further identification required	Unknown		1
Cnidaria				
Order Hydrozoa	*Tubularia sp.*	Unknown		1
Order Scleractinia: Hard Coral	*Tubastrea coccinea*	Alien		1
	Further identification required	Alien		1
Order Actinaria: Family Actiniidae				1
Large red anemone	*Bunodosoma caissarum*	Alien		1
Small anemone	*Anemonia melanaster*	Alien		2
Echinodermata				
Family Amphiurudae (brittle star)	Class Ophiuroidea	Alien		1
Cushion star	*Asterina stellifera?*	Alien		1
Slate pencil urchin	*Eucidaris tribuloides*	Alien		1
Rock boring urchin	*Echinometra lacunter*	Alien		1
Black urchin	*Arbacia lixula*	Alien		1
Crustacea				
Order Cirripedia: Barnacles				
Family Balanidae	*Megabalanus tintinnabulum*	Alien		3
Family Balanidae	*Balanus sp.*	Alien		1
Family Tetraclitidae	*Tetraclita sp.*	Alien		1
Order Amphipoda				
Family Colomastigidae	Further identification required	Probably alien		1
Family Corophiidae	*Aora spinicornis?*	Probably alien		1
	Gammaropsis sp.	Probably alien		1
Family Dexaminidae	Further identification required	Probably alien		1
Family Eusiridae	Further identification required	Probably alien		1
Sub-order Gammaridea	Further identification required	Probably alien		1
Family Ischyroceridae	*Jassa sp.*	Probably alien		1
Order Isopoda				1
Family Anthuridae	*Mesanthura sp.*	Probably alien		1
Family Sphaeromatidae	*Cymodocella sp.*	Probably alien		1
	Dynamenella sp.	Probably alien		1
Suborder Caprellidea		Probably alien		1
Family Aeginellidae				
Order Decapoda				
Alpheid shrimp	*Synalpheus sp.*	Alien		1
Cuban stone crab	*Menippe nodifrons*	Alien		1
Porcelain crab	*Pachycheles laevidactylus*	Alien		3
Family Majidae:	*Stenorhyncus seticornis*	Alien		1
Spider crab	Further identification required	Alien		1
Pycnogonida				
Family Nymphonidae (Sea Spiders)	*Nymphon sp.* or *Tanystylum sp.*	Probably alien		1

Table 1 continued

Group	Species	Alien or native	Reference	Assessed risk level
Nemertean worms				
Family Lineidae?	*Lineus sp.*	Probably alien		1
Sipunculid worms				
Class Phascolosomatidea (Peanut worms)	*Phascolosoma sp.*	Probably alien		1
Platyhelminthes (flat worms)				
Family Procerodidae?	*Procerodes sp.*	Probably alien		1
Annelida				
Polychaete worms				
Family Capitellidae (Lug Worms)	Further identification required	Probably alien		1
Family Eunicidae (Rock Worms)	*Eunice sp.*	Probably alien		1
Family Nephtyidae	*Nephtys sp.*	Probably alien		1
	Further identification required	Probably alien		1
Family Nereidae	*Nereis sp.*	Probably alien		1
Family Orbiniidae	Further identification required	Probably alien		1
Family Phyllodocidae	*Phyllodoce sp.*	Probably alien		1
	Protomystides sp.	Probably alien		1
Family Serpulidae (Plume Worms)	Further identification required	Probably alien		1
Family Syllidae	*Syllis sp.*	Probably alien		1
Bivalves				
Family Anomiidae (Saddle Oysters)	Further identification required	Alien		1
Family Arcidae (Ark Shells)	*Barbatia sp.*	Alien		1
Family Chamidae (Jewel boxes)	Further identification required	Alien		1
Family Glycymerididae (Bittersweet Clams)	Further identification required	Alien		1
Family Mytilidae (Scissor date mussel)	*Lithophaga nasuta?*	Alien		1
Scissor date mussel	*Lithophaga/Myoforceps aristata*	Alien		1
Brown mussel	*Perna perna*	Alien		1
Family Ostreidae (Oysters)	*Crassostrea sp.*	Alien		1
Family Spondylidae (Thorny Oyster)	*Spondylus sp.*	Alien		1
Family Veneridae (Venus clam)	*Dosinia hepatica*	Alien		1
Venus clam	*Irus irus?*	Alien		1
Cephalopoda (octopus)	*Octopus vulgaris*	Probably native		
Gastropoda (Snails)	Further identification required			
Gastropod - small		Alien		1
Red-lipped whelk	*Thais (=Stramonita) haemastoma*	Alien		1
Bryozoa				
Family Bicellariellidae?	*Bicellariella ciliata?*	Unknown		1
Tunicata				
Large seasquirt	*Microcosmus exasperatus?*	Alien		1
Pisces (fish)				
Silver porgy	*Diplodus argenteus argenteus*	Alien		4
Variable blenny	*Parablennius pilicornis*	Alien		4

? denotes uncertainty about the specific identity given specimens of red algae were also collected. Many of the small crabs collected in samples in September/October 2006 were carrying eggs. Barnacles were observed mating and blennies were carrying eggs and guarding nests in January/February 2007.

Prominent, easily seen (especially mobile) species were removed from the rig during the first survey. Six of the species found on the rig in September/October 2006 were not seen in the following December/January, including four of five echinoderms and both gastropods (Table 1). Additionally, numerous bivalve shells appeared to have been preyed upon and we observed one predation event involving the native whelk *Argobuccinium tristanensis* attacking an alien oyster *Crassostrea sp.*

A few native species had already begun to colonise the rig by the time of the first survey, 3–4 months after its stranding (Table 2). Numerous kelp *Macrocystis pyrifera* and *Laminaria pallida* sporelings and the red alga *Schimmelmannia elegans* were found on the upper 2–4 m of the rig, while several small octopus and rock lobster were collected. On the second survey large octopus and a few large rock lobster were seen on the lower legs around at around 13 m depth.

Table 2 List of marine species native to Tristan observed on or around the rig

Group	Species
Algae	
Sea Lettuce	*Ulva lactuca*
Kelp sporelings	*Macrocystis pyrifera* and *Laminaria pallida*
Poriferan	
Sponge	*Unknown spp.*
Crustacean	
Tristan Rock Lobster	*Jasus tristani*
Asteroid	
Star-fish	*Henricia simplex*
Gastropod	
Whelk	*Argobuccinium tristanensis*
Cephalopod	
Octopus	*Octopus vulgaris*
Pisces	
False Jacopever	*Sebastes capensis*
Klipvis	*Bovichtus diacanthus*
Tristan Wrasse	*Nelabrichthys ornatus*
Five-finger	*Acantholatris monodactylus*

In all, 62 alien taxa were recorded on the rig (Table 1). Identification difficulties meant that in some instances, taxa were identified to family level only. Thus the total number of unique taxa represents a minimum estimate of the number of alien species present. No alien species were found during monitoring dives in Trypot Bay in 2007.

Risk assessment

Several species (two finfish, several unidentified crabs and a barnacle) were assessed to be at invasion stage three (medium risk) or four (high risk of becoming invasive). Mating events of the acorn barnacle and the presence of berried (with eggs and/or larvae) crabs moot the possibility that planktonic larvae will settle and become established, and these are thus at stage three.

Two finfish species are, however, at stage four of invasion. On the second survey, several individuals of the variable blenny were observed to be in breeding condition (eggs ripe and running) and one was found guarding eggs that had been laid in an empty barnacle shell on the rig. We also encountered five individuals *ca* 50 m from the rig (three of these were collected). It is thus possible that this species had moved off the rig before it was removed in numbers sufficient to establish a viable naturalised population.

The alien silver porgy *Diplodus argenteus argenteus* (Sparidae), estimated to exceed 60 in number, remained closely associated with the rig structure despite shoaling with local fish. Three porgy were collected using spearguns, ranging in size between 8 and 32 cm, with the largest specimen a mature male. We had hoped that the remaining fish would move with the rig and not return to the inshore environment after the rig sank. However, a single specimen was caught at the Tristan settlement (at the opposite side of the island to Trypot Bay) in May 2007, indicating the strong possibility that some individuals have persisted in the Tristan environment and there is also a high risk that they too will become invasive on Tristan.

Terrestrial alien species

There was plenty of food in the kitchen, such as open bags of rice, decomposing fruit, half-eaten plates of food, etc. accessible to rodents, insects and other hitchhiking species. Four dormitories contained open packets of food (mostly biscuits and sweets) and

Table 3 List of insects collected from the rig

Group	Species	Alien or native	Comments
Diptera			
Family Sciaridae (mosquito-like flies)	Unknown	Probably Alien	Need to confirm previous presence on Tristan
Family Drosophilidae (fruit flies)	Unknown	Probably Alien	Need to confirm previous presence on Tristan
Family Muscidae (house flies)	Unknown	Probably Alien	Need to confirm previous presence on Tristan
Blattodea			
Cockroach	*Blatta sp.*	Alien	Probably dead on arrival. Likely to already be present on Tristan

elsewhere decomposed remains of edible vegetables were found. None of the food or containers (with and without food inside) contained any rodent faeces and none had signs of having been gnawed-at or eaten by rodents or invertebrates. There were no signs of other organisms present in the food. Several species of fly (Diptera), some of which were still alive, and a dead cockroach (Blattodea) were collected from inside a refrigerator (Table 3).

Discussion

This decade has seen a dramatic rise in oil prices, which in turn has driven an unprecedented rise in the rate of semi-submersible rig transport (Morgan 2005; Meuller 2007). To the best of our knowledge, it is not common practice to remove biofouling organisms before rigs are towed (P. Holloway pers. comm. to RMW). Our findings reveal how semi-submersible rigs that are towed across marine biogeographic boundaries present opportunities for the spread of alien species to an astonishing array of organisms. Had the rig not become stranded on Tristan, but instead reached its destination, the port of Singapore, the probability is that many species that survived the tow would have found the warm-water conditions there very similar to the source waters in Macae, Brazil (David et al. 2005), and we speculate that the invasion risks would have been even higher than at Tristan.

This is the first time that a major marine salvage operation has been undertaken largely as a result of concerns over invasive species. The liability insurance cost for underwriting the salvage operation amounted to *ca* US$20 million (P. Holloway, pers. comm. to RMW). By comparison, the expected monetary costs of removing encrusting organisms from the rig prior to departure would have been completely trivial. In addition, insurance liability has not ended with the removal of the rig from the photic zone around Tristan. If any species brought by the rig become invasive and have a negative impact on the Tristan economy, substantial additional claims are likely.

Marine alien species

Initial examination of the rig revealed a high level of colonisation and wide diversity of fouling marine life, mostly alien to Tristan, with many animals still alive and healthy, and some in breeding condition. This gave rise to great concern over the risk of permanent settlement of alien species, and the possible adverse effects on local species, ecosystems and fisheries. These concerns led to the decision to scuttle the entire rig in very deep water, as the best action to limit the possibility of alien marine species settling on Tristan. However, these individuals had survived a Tristan winter, with water temperatures as low as 13–14°C; temperatures in the source waters range from 13–27°C (David et al. 2005). Changes in temperature (both rise and fall) are known to stimulate breeding in many marine species, and spawning events are known to have taken place before the rig was sunk. It is too early to establish whether these will result in successful establishment, and if so, whether there will be any adverse effects. The reason for the disappearance of some species can only be speculated upon, but is likely a combination of factors, with rough seas, lower water temperature and predation likely to play a role.

Allee effects occur when species occur at densities too low to allow individuals to meet and reproduce (Courchamp et al. 1999). They may survive individually, but reproduction occurs too infrequently to permit the establishment of a viable population. It is possible that this will prevent establishment of the acorn barnacle, because although it was seen mating, it is an internal fertilizer, and thus requires reasonable densities for successful reproduction (Foster 1987). However, the case for Allee effects should not be overstated—most species have evolved effective mechanisms for ensuring successful meeting of potential mates/gametes (Drake and Lodge 2006). Although monitoring may help to reveal the presence of any recruits, highly motile larvae could become established anywhere within the Tristan group, and eradication or control are unlikely to be practical after colonisation occurs.

The variable blenny probably stands the highest risk of becoming invasive. According to FishBase, it has an amphiatlantic distribution, subtropical to 35° S, and typically inhabits rocky coasts, often at steep walls of surf-exposed sites, a habitat mimicked by conditions on the rig legs (Froese and Pauly 2008). Therefore many locations around the coast of Tristan would seem to be suitable for this species. It also reproduces quickly, with a minimum doubling time of less than 15 months (Froese and Pauly 2008). The natural range of this fish is the West Atlantic from Florida to Argentina (35° S), so it may be near the limits of its tolerance on Tristan (Springer 1986).

Silver porgy occurs in clean turbulent waters along open rocky coasts (an abundant habitat on Tristan), usually in surf areas, and juveniles are frequently caught in seashore pools between rocks and in sandy areas (Ferreira et al. 2004; Rangel et al. 2007). They have a minimum doubling time 1.4–4.4 years, and become sexually mature at *ca* 20 cm (David et al. 2005; Froese and Pauly 2008), so most individuals around the rig were already mature. They are digynous protandrous hermaphrodites (start off male then become female) and females are multiple spawners. In Cabo Frio, which is close to Macae, reproductive activity occurs from late winter to summer, following coastal upwelling (David et al. 2005). This species is considered an important driver of community structure in Brazil (Ferreira et al. 2004) and is thus of great concern for the Tristan marine environment.

At present there is no demonstrable risk to the Tristan rock lobster fishery. Also, there are no measurable impacts from potentially invasive species on any other aspects of the marine environment. However, it is early days yet, and we have identified at least three species that are advancing towards becoming fully established, and thus potentially invasive, in the waters around Tristan. Thus negative impacts could still accrue. Furthermore, parasites and diseases may also become apparent, and Tristan's marine biosecurity will remain at potential risk for an unknown period.

We are encouraged by our failure to find any alien species near the site of the stranded rig 9 months after the rig was removed; however, our search was by no means exhaustive, and newly-settled invertebrates would still be small and/or localised. Ongoing monitoring of an invaded site is essential, until further signs of establishment or invasion are unlikely to be detected (Bax et al. 2001). However, the timeframe for monitoring will vary according to the lifecycle of the species of concern. We propose a detectability threshold be assessed for all species in risk categories 2–4, which will determine how long it is likely to take for a viable population of alien organisms to become detectable. Using expert knowledge, the colony or population size for probable detection in a general survey should be estimated. Population growth rates or, if these data are lacking, developing a deographic model for each species to estimate likely growth rate, will allow one to calculate the probable intersection time between population growth and detectability. We suggest that conservatively the monitoring period should continue for 25–50% longer than that time. Monitoring of established alien species (risk category 4) should continue for as long as that species is present. Part of the monitoring process in the longer-term should involve the collection, for further analysis, of organisms such as the Tristan rock lobster, should signs of parasitic or other infestation/infection become apparent at any time in the future. This would allow comparison with specimens collected during the 2006/07 survey, and possibly indicate if any link between the rig stranding and the disease exists.

Terrestrial alien species

There appeared to be no rodents living aboard the rig before departure, and none came aboard during the towing. Similarly, no rodents from the island had access to the rig. The tow-preparations could have facilitated establishment of the highly mobile, human-commensal insect species we recorded on the rig. However, the time that elapsed between the commencement of towing (at which point the rig would have been deserted by people) and its arrival on Tristan appears to have been too long without fresh food, and the evidence suggests that the majority of insects that may have been alive at departure were dead by December 2006, and possibly before arrival on Tristan. From a terrestrial biosecurity perspective, the stranded rig did not appear to have introduced any alien species to the Tristan environment.

Conclusion

It is recommended that as a basic precaution to prevent (or minimise) the spread of invasive alien species associated with the movement of rigs encrusting/biofouling organisms should be physically removed or otherwise killed (e.g. by prolonged immersion in freshwater or exposure to air) immediately prior to towing. Aside from biodiversity concerns, such an action has potentially significant economic advantages. Fouling drag can add 20–30% to the time for a tow to be completed (Townsin 2003), amounting to significant labour and fuel costs, which should more than offset the costs of cleaning. This should be made standard practice for all pre-towing contracts and, given the extreme expenses demonstrated by this study, we expect that the maritime insurance industry should become proactive in regulating this.

Acknowledgments The Captains and crew of the fishing vessels M.V. Kelso and the M.V. Edinburgh, staff from Ovenstones Agencies and the Salvage Master and members of the Titan salvage crew all provided invaluable support. The Tristan Administrator at the time, Mike Hentley, members of the Island Council and residents of Tristan are thanked for their assistance and hospitality. Peter Holloway worked closely with the second survey team to ensure the success of work above- and below-water. The following assisted with identification: Rob Anderson (algae), Wouter Holleman and Phil Heemstra (fish), Peter Wirtz (invertebrates and fish) and Ashley Kirk-Spriggs (insects).

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