Species Introductions and Potential for Marine Pest Invasions into Tropical Marine Communities, with Special Reference to the Indo-Pacific[1]

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Abstract: Introductions of marine species by hull fouling or ballast water have occurred extensively in temperate areas, often with substantial deleterious impacts. However, current information suggests that marine introductions potentially able to achieve pest species status have been fewer in tropical regions. A 1997 risk assessment examining introductions to 12 tropical ports in Queensland (Australia) concluded that far fewer marine species appeared to have been introduced, even at major bulk export ports where the number of ship visits and volume of discharged ballast water are more than at most of Australia's cooler water ports. Results from recent surveys looking for introduced species in tropical ports across northern Australia are beginning to support this conclusion, although the lack of historic baseline surveys and the poor taxonomic status of many tropical groups are preventing a precise picture. The 1997 report also concluded that, apart from pathogens and parasites of warm-water species, the potential for marine pest invasions in Queensland tropical ports appeared to be low, and not only because much of the discharged ballast water originates from temperate ports in North Asia. In contrast, recent surveys of harbors in Hawai'i have found over 110 introduced species (including 23 cryptogenic species), the majority in the estuarine embayments of Pearl Harbor and O'ahu's commercial harbors. We suggest that the biogeographically isolated and less diverse marine communities of Hawaiian ports have been more susceptible to introductions than those of tropical Australia for several reasons, including the closeness of Australia to the central Indo-Pacific "triangle" of megadiversity (Indonesia-Philippines-Papua New Guinea) and consequent high biodiversity and low endemicity, hence offering fewer niches for nonindigenous species to become established. The isolated central Pacific position of Hawai'i and its long history of receiving worldwide commercial and naval shipping (including more heavily fouled vessels than contemporary merchant ships) is another key factor, although the estuarine warm-water ports of Townsville, Brisbane, and Darwin also provided anchorages for military units during World War II. Hull fouling remains an important vector, as it is the most likely cause of the recent transfer of the highly invasive Caribbean black-striped mussel (*Mytilopsis sallei*) to enclosed (lock-gate) marinas in Darwin by international cruising yachts arriving via the Panama Canal. The cost of eliminating this pest (>US$1.6 million) underscores the importance of managing not just commercial shipping but also pleasure craft, fishing boats, and naval ships as vectors of exotic species to ports, harbors, and marinas in coral reef areas.

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MARINE SPECIES HAVE been transported and introduced into new areas since vessels began sailing between regions. These species were initially carried on wooden hulls as fouling organisms, then with "dry ballast" taken from beaches and rocky shores, and, during the twentieth century, in the ballast water of increasingly larger and faster merchant ships. Other vectors responsible for marine species introductions include the transfer and culture of shellfish, accidental or intentional release or dumping of aquarium species, and relocation of floating docks and drilling rigs. Although ship-related introductions were recognized from 1908 (Ostenfeld, in Cawthron Institute 1997), it was not until the 1970s with the increasing use of faster and larger bulk carriers, tankers, and containerships and a concomittant rise in the volume and "quality" of ballast water discharged into ports (>180 million tonnes per annum for Australia [Patterson and Colgan 1998]) that large numbers of nonindigenous species began to be reported primarily in temperate estuarine ports (e.g., Hoese 1973, Medcof 1975, Carlton 1985, Carlton and Geller 1993, Ruiz et al. 1997, Patterson and Colgan 1998).

An introduced species is considered invasive if it tolerates a range of local environmental conditions, forms a common component of the habitats and communities into which it spreads, and/or colonizes a relatively wide geographical area (e.g., Thompson 1991, Hilliard et al. 1997, Ruiz et al. 1997). Whether or not it also gains the status of a "nuisance species" (United States/Canada) or "marine pest" (Australia/New Zealand) depends on the perceived type and extent of ecological or socioeconomic disruptions that its new populations cause. As with their terrestrial counterparts, invading marine species typically achieve such status by their competitive prowess, sheer density, toxicity, or other noxious traits.

Large numbers of introduced species have now been documented for temperate ports and harbors in Australia, New Zealand, Europe, and North America, of which 5–15% have achieved "pest" or "nuisance" status depending on location (e.g., see Ruiz et al. 1997, Hilliard 1999, Hutchings 1999). Many have now spread far from the ports where they were first introduced, and there are no effective measures for eradicating established populations of nonindigenous species except in localized sites amenable to intensive management (e.g., Pyne 1999, Culver and Kuris 2000). Current effects on local ecosystems and fisheries range from basinwide severe impacts in temperate areas (e.g., North American comb jellyfish in the Black Sea and the European zebra mussel across U.S. watersheds) to restricted and as yet unclear impacts in tropical regions (e.g., black-striped false mussels [*Mytilopsis sallei*] and Senhouse date mussels [*Musculista senhousia*] colonizing disturbed and polluted harbor habitats in Asian ports, including Singapore, Hong Kong, Manila, Tokyo Bay, and Venkitsalam [Morton 1987, Asakura 1992, Furlani 1996, Chu et al. 1997, Hilliard et al. 1997; R. Willan, Northern Territory Museum, pers. comm.]).

Documentation of marine introductions and their effects has been more comprehensive in temperate regions, in part because the native fauna and flora are usually well known, and because local sources of funds and taxonomic expertise have enabled focused field surveys. In comparison few surveys have been undertaken in the Tropics to document marine introductions until very recently. Among the first were Coles et al.'s (1997, 1999*a,b*) surveys of Pearl Harbor and other Hawaiian harbors in the Hawaiian Islands, which found that 95–100 species (17–23%) of the total flora and fauna in the harbors were either introduced or cryptogenic (of uncertain origin). However, surveys in harbors with more open circulation and oligotrophic conditions at Midway Atoll (DeFelice et al. 1998), Kaho'olawe Island (Coles et al. 1998), and Johnston Atoll (Coles et al. 2001) have found the nonindigenous/cryptogenic component of the total biota to be 1% or less. This suggests that environmental conditions in a harbor and type and frequency of ship traffic are of major importance as determinants of introduction success and dominance of the harbor community.

Virtually all nonindigenous species surveys in Australia were focused on temperate waters (e.g., see Pollard and Hutchings 1990*a,b*)

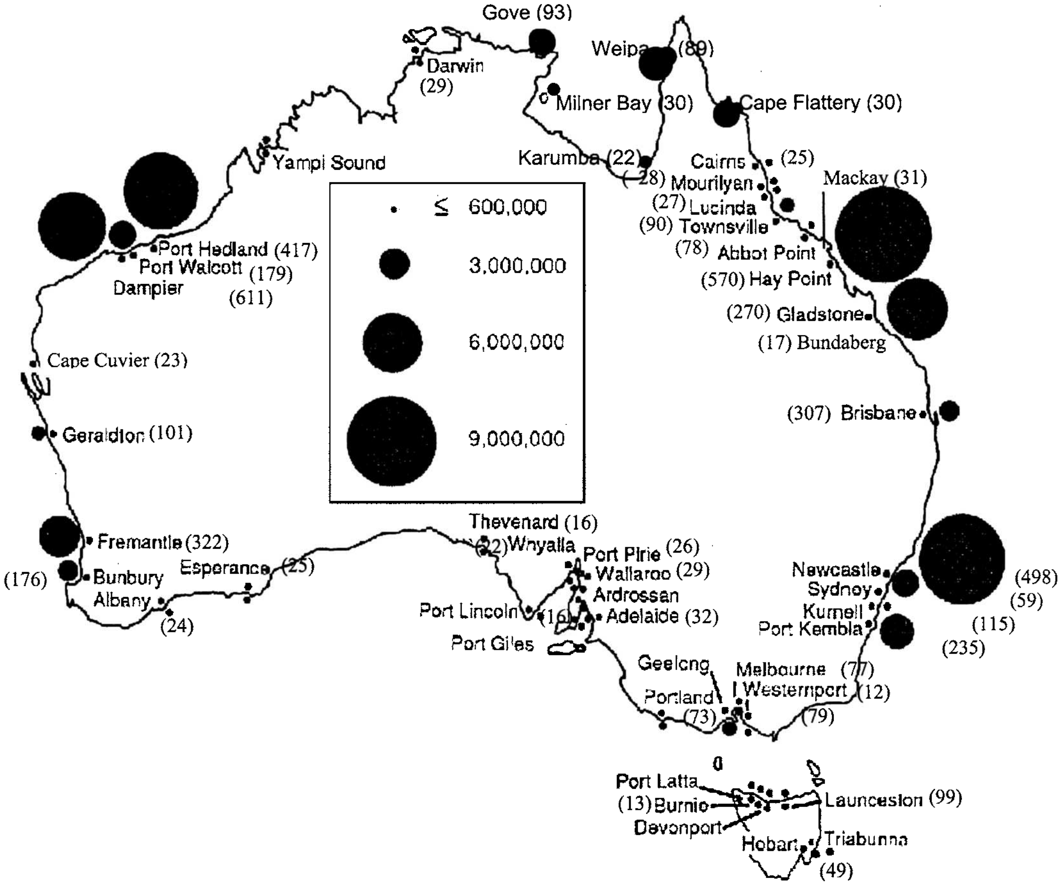

FIGURE 1. Annual ship visits and metric tonnages of ballast water discharged at ports with export terminals around Australia (modified from diagrams in AQIS 1992 and data in Kerr 1994 and Hilliard et al. 1997). Crude oil export terminals on the Northwest Shelf are not shown.

until introduced marine species became recognized as a national problem during the mid-1990s, after which studies and port surveys were commenced in regions around the continent. However, many of the port surveys completed to date have highlighted the fact that historical baseline data for the naturally occurring biota do not exist for many areas. An exception was the recent survey of Port Phillip Bay near Melbourne (Victoria). This study was able to compare the current biota with records collected during the late 1960s, and several new nonindigenous species were found (Wilson et al. 1998), highlighting the importance of historical records for identifying recently established nonindigenous species. Lack of baseline data has been most apparent for the tropical ports, several of which are the largest in Australia in terms of number of ship visits and volume of discharged ballast water (Figure 1). For example, recent baseline surveys at the ports of Abbot Point and Mourilyan (North Queensland) found that 84% of the Polychaeta (a dominant component of the benthic fauna) could not be identified to species, highlighting the limited knowledge of the fauna.

Documenting all marine biota of tropical Australia and other parts of the Indo-Pacific to help identify native species, confirm their distribution, and so elucidate the true extent of nonindigenous species introductions will probably take decades owing to the limited amount of taxonomic expertise and funding sources. Because most marine nonindigenous species have been reported from temperate rather than tropical areas, it is unclear if the apparently lower numbers of marine species introductions (including "pest invasions") in tropical Australia are purely a function of the smaller number of studies. Lines of evidence have started to emerge, however, that tropical ports may be more resistant to marine introductions, at least in the central Indo-West Pacific. Reasons include their high biodiversity and apparent homogeneity (i.e., containing many estuarine, coastal, and reef species with widespread distributions compared with the more restricted biota in the equivalent habitats of temperate areas). On the other hand, as taxonomic work on tropical marine biota slowly progresses, it appears that, at least for the more sedentary organisms such as polychaete worms, taxa previously thought to be represented by one widely distributed species comprise several closely related species (Hutchings and Peart 2000).

EVIDENCE FROM TROPICAL PORTS IN THE GREAT BARRIER REEF REGION

One of the first studies to examine the question of marine introductions in tropical areas was initiated by five Queensland Port Authorities, led by the Ports Corporation of Queensland. This group commissioned a ballast water risk assessment to investigate the potential for marine pest invasions at 12 ports in the tropical region of Queensland (Hilliard and Raaymakers 1997, Hilliard et al. 1997). All but two of the ports lie on Queensland's east coast adjacent to the Great Barrier Reef and within the Great Barrier Reef World Heritage Area. The distances of these ports and other Australian ports to the nearest coral reef community are listed in Table 1.

The 12 Queensland ports range from those with an estuarine setting (Bundaberg, Cairns, Karumba, Mourilyan, Rockhampton, Townsville, Weipa) to those where the ballast water is discharged at the end of long jetties (>2 km) where fully marine conditions occur (Abbot Point, Lucinda, Hay Point). Australia's tropical estuarine ports experience marked seasonal flushing due to the alternation of relatively short-period summer monsoonal rains with long "winter" dry seasons when the southeasterly trade winds predominate (Hilliard et al. 1997). The study determined the amount and origins of ballast water discharged into each port between 1989 and 1995, compared their environmental characteristics with the main overseas ballast water "source" ports, and used the CSIRO-Centre for Research on Introduced Marine Pests (CRIMP) database to help identify and assess all available records of known or suspected introductions in tropical, subtropical, and temperate Australian waters.

In the context of the potential for marine introductions to lead to at least one marine pest invasion, it can be seen from national lists of declared marine pests or "nuisance organisms" that these comprise species that are: (1) widespread (= reasonably common and widely distributed within its native range); (2) tolerant (= can withstand a relatively broad range of physical conditions including temperature and salinity, and often having a tough or quiescent stage well adapted for dispersal and/or surviving extreme conditions, respectively); (3) generalist (= able to feed on a wide range of food, often filter feeders); (4) competitive (= outcompete/overwhelm native taxa by developing dense populations [shading, smothering, substrate alteration, predation, or excessive water column filtration] that are achieved by higher reproductive output, growth rate, and/or impunity to predators, parasites, or diseases); (5) pioneering (= among the first to colonize or utilize disturbed and "vacant" habitats).

The Queensland port study suggested that the ability of a potential pest species to invade a particular port will vary according to: (1) the degree of biophysical similarity between its native range and that available in or close to the port of introduction (critical parameters include extreme maximum and minimum temperatures, salinities, dissolved oxygen levels, sediment stability); (2) the genetic fitness/robustness of the introduced species relative

TABLE 1

Distances between Export Berths and Nearest Coral Communities in Northern Australia

Port Trade	Location	Nearest Hard Coral Community
Queensland Ports[a]		
Mixed bulk and trade	Brisbane	45 km (to Herald Reef at mouth of Moreton Bay)*
Bulk wheat and sugar	Bundaberg	60 km (to southern end of Great Barrier Reef)
Mixed bulk	Gladstone	18 km (on rocky reefs south of entrance channel)*
Mixed trade	Rockhampton	22 km (on rock reef; 32 km to carbonate reefs)
Bulk coal	Hay Point	25 km (on rock substrate)*
Bulk wheat and sugar	Mackay	2.5 km (on rock substrate)
Bulk coal	Abbot Point	15 km (on rock substrate)
Mixed bulk and trade	Townsville	3.7 km (on rock substrate; 6 km to carbonate reef)*
Bulk sugar	Lucinda	9 km
Bulk sugar and livestock	Mourilyan	0.5 km (on rock substrate; 9 km to carbonate reef)*
Mixed trade	Cairns	<10 km (on fringing reef; 19 km to coral cay)*
Bulk silica sands	Cape Flattery	0.5 km (on rock substrate; 14 km to coral cay)
Bulk bauxite	Weipa	11 km (on coastal reef; 65 km to carbonate reefs)*
Bulk mineral concentrate	Karumba	>100 km (no coral in southeast Gulf of Carpentaria)*
Other Northern Australian Ports[b]		
Northern Territory[c]		
Bulk manganese	Milner Bay (Groote Is.)	1 km (nearshore rocky substrate reefs)*
Bulk alumina and bauxite	Gove	<2 km (carbonate reefs on edge of shipping channel)*
Mixed trade	Darwin	<4 km (rocky substrate reefs in outer harbor area)*
Western Australia[d]		
Mixed trade	Wyndham	>40 km (outer Cambridge Gulf, Kimberley Region)
Mixed trade	Broome	7 km (on fringing rock reef near Gantheaume Point)*
Bulk iron ore, salt	Port Hedland	>30 km*
Bulk iron ore, salt, LNG	Dampier	0.5 km (to fringing reefs in Mermaid Sound)*
Oil export terminal	Airlie Island	<2 km from offshore mooring array*
Oil export terminal	Varanus Island	<3 km from offshore mooring array*
Oil export terminal	Thevenard Island	<3 km from offshore mooring array*
Oil export terminal	Barrow Island	<4 km from offshore mooring array*
Bulk solar salt	Point Cuvier	2 km (rocky fringing reefs)
Bulk solar salt	Useless Loop, Shark Bay	<20 km (small patch reefs in Useless Inlet)*
Bulk grain and minerals	Geraldton	48 km (to closest Albrohlos Island carbonate reefs)*

[a] From Hilliard et al. (1997) and fieldwork (R.W.H.*); ports are listed from south to north; see Figure 1.
[b] From charts and fieldwork (R.W.H.*).
[c] Ports listed from east to west.
[d] Ports listed from northeast to southwest.

to any local counterparts or sibling taxa that may be present; (3) the inherent ability of the local communities to resist invasion via biological "defense pressure" (e.g., presence of local species competing for space or food, or capable of consuming, parasitizing, or infecting one or more of the critical life-cycle stages of the introduced species); and (4) the health and stress status of the local communities, including the amount of disturbed/vacant habitat in the receiving environment due to recent natural events or human activities.

The study also concluded that none of these Queensland ports appeared to be suffering from marine invasions on the scale and impacts as those occurring in many of the temperate ports of southern Australia and New Zealand. In fact, numbers of both total nonindigenous species and declared pests decrease rapidly north of Sydney-Newcastle on Australia's east coast and north of Fremantle on the west coast. This decline is not related to shipping activity (more ballast water is discharged into many of Australia's tropical ports than its temperate ones and ship visits are also more frequent at most of the major export ports in the Tropics [Figure 1]).

Most of Australia's major tropical ports have been operating for at least 25 yr, and there is also reasonable evidence indicating that absence of nuisance or "pest" species incursions is not the result of fewer people capable of recognizing these in the tropical ports. The Queensland study put forward some plausible explanations as to why they had so far apparently escaped a substantial invasion: (1) Physical stresses in the sub-equatorial latitudes (10–23°) of Australia's northern ports are strong, particularly for estuaries and coastlines exposed to "seasonal" but often irregular patterns of high insolation, temperature, desiccation, and salinity interspersed by cyclones and bouts of intense monsoonal rainfall. The latter often causes extremes in terms of wave action and substrate scouring, turbidity, and sedimentation, and precipitous declines in salinity and dissolved oxygen. (2) Levels of biological competition and defenses appear higher in tropical communities. These are due to higher species numbers and degrees of niche specialization, occupation, and overlap compared with their temperate counterparts (Hatcher et al. 1989). This may mean that Queensland coastal communities may offer fewer opportunities for nonindigenous species to develop sustainable populations compared with temperate communities. (3) The high diversity and low endemicity exhibited by Queensland coastal communities, which are part of the central Indo-West Pacific biogeographic region, may inhibit the successful colonization of non-native species.

The characteristics listed here led the authors of the Queensland port study to propose the hypothesis that the "well connected" and biodiverse tropical communities of the central Indo-West Pacific region may be less at risk to pest invasions than biogeographically isolated marine communities where species endemism is higher, diversity is lower, and opportunities for robust new arrivals greater. The hypothesis was restricted to free-living multicellular organisms and excludes pathogens and parasites, where different factors may operate.

The conclusion that the northern Australian ports have relatively few nonindigenous species and may be less prone to marine pest invasion has been lent support from the results of recent surveys of several tropical estuarine and bulk export ports, including Abbot Point, Dampier, Darwin, Mourilyan, and Weipa (e.g., Hewitt et al. 1998, Hoedt et al. 2000, Russell and Hewitt 2000; F. Wells, Western Australian Museum, pers. comm.). For example, a recent survey of Hay Point, which receives over 430 bulk carrier arrivals discharging over 14 million tonnes of ballast water annually (Hilliard and Raaymakers 1997), found only six cosmopolitan nonindigenous species and four possibly introduced (cryptogenic) organisms from over 495 taxa identified to species level (Hewitt et al. 1998).

CARIBBEAN BLACK-STRIPED MUSSELS IN THE PORT OF DARWIN

The Queensland ports study restricted its focus on hull fouling to the incidence of in-water hull cleaning and chain locker/anchor washing on merchant ships (see Carlton 1985), because many modern ships use efficient organotin antifouling paints to maintain smooth hulls for minimizing fuel consumption. Compared with the majority of merchant ships, however, the hulls of itinerant fishing vessels and international cruising yachts can be more prone to fouling. Two recent incidents involving transfer of the Caribbean black-striped false mussel (*Mytilopsis sallei*) to the Port of Darwin in northern Australia (Pyne 1999) highlight the fact that hull fouling per se remains an important vector.

The first incident was a serious infestation inside two of Darwin's lock-gate marinas between September 1998 and April 1999. The mussels are thought to have been transferred on the hull of either one of three international cruising yachts arriving in Darwin in 1998 from the Panama Canal (Pyne 1999) or from an unidentified Indonesian fishing vessel (R. Willan, Northern Territory Museum, pers. comm.). The second incident was the discovery in September 2000 of the same species in Darwin, this time on the hull of two itinerant Indonesian fish freezer support vessels (R. Willan, Northern Territory Museum, pers. comm.), which were subsequently refused entry into State waters.

During the first incident the rapidly reproducing and fast-growing *Mytilopsis sallei* achieved very high densities within the marinas (>10,000 per m^2) over the 5–6 months before its discovery and subsequent eradication by sodium hypochlorite and copper sulphate dosing. Its apparent total absence beyond these recently opened artificial harbors has posed questions as to why it failed to colonize natural intertidal or sublittoral habitats outside the lock gates where >7.5-m tides occur (Hilliard 1999). However, the potential for this salinity-tolerant invader to cause major ecological and economic impacts if it spread to more conducive habitats in other ports cannot be downplayed, and all vessels that had left the infected marinas (743) were located and those found infected were cleaned. Some boats had reached Port Douglas in North Queensland and another had reached Sydney. The cost of the eradication program and subsequent monitoring and checking exceeded US$1.6 million.

The Darwin incidents highlight the need for ongoing vigilance, particularly for yachts and fishing vessels that undertake long voyages between lengthy periods at anchor (Rainer 1995, Walters 1996, Cawthron Institute 1997, Pyne 1999). Cawthron Institute (1997) cited the arrival of a Russian trawler at Auckland (New Zealand) with over 90 tons of biofouling that had accumulated during its previous layup in the Black Sea. Where yachts and fishing boats are often slipped for hull cleaning, the typical absence of suitable devices to retain all scrapings means that much of the biota gets washed back into the harbor. The owner or crew of itinerant fishing boats and international cruising yachts may also elect to clean up the hull in a sheltered bay, either by snorkeling/scuba or when beached during a low tide.

EVIDENCE FROM OTHER TROPICAL PORTS

Data from the recent surveys of Pearl Harbor and other O'ahu ports show that tropical marine nonindigenous species from the Indo-West Pacific and Caribbean regions currently make up ~40% and 10%, respectively, of the total nonindigenous species recorded at Hawai'i (Coles et al. 1999*a,b*).

The Hawaiian data lend some support to the idea that biogeographically isolated communities in ports and harbors are more susceptible to exotic species introductions. Also, Coles et al. (1999*a*) noted that the higher number of exotic species found in Hawai'i in comparison with northern Australia may also be related to Hawai'i's essentially subtropical, rather than true tropical, climate regime. Introduction of tropical exotic species to isolated "subtropical" Hawai'i begs comparison with the eastern Mediterranean following the opening of the Suez Canal, where many tropical nonindigenous species from the Red Sea have become established (Galil 2000). Before the rise of shipping and opening of the Suez Canal the Mediterranean Sea was relatively isolated, with a relatively low diversity of marine biota (Baltz 1991, Hilliard et al. 1997). It is also interesting that, of the wide range of marine nonindigenous species that have become established in Hawai'i and the eastern Mediterranean (Boudouresque et al. 1995, Galil 2000), the most prolific and worrisome have been the red and green macrophytes, respectively (Doty 1961, Brostoff 1989, Russell 1992, Rodgers and Cox 1999, Smith et al. 2002). In the case of Hawai'i, none of the marine introductions is considered to have achieved a marine pest status either within or outside the harbors (Coles et al. 1999*a,b*), although five species of nonindigenous red algae have proliferated on some inshore reefs and rocky shorelines, particularly where nutrient levels have been elevated (e.g., Kāne'ohe Bay [Rodgers and Cox 1999]). Nutrient-stimulated proliferation of algae can smother corals, and this provides an example of how disturbance can place tropical habitats and communities at increased risk from nonindigenous species.

Most ports in northern Australia are close to coral communities (and in a few cases also close to true carbonate coral reefs [Table 1]). The potential for an introduced species to colonize these areas remains unclear because the results from Hawai'i and the Port of Darwin remain ambivalent, particularly with respect to relatively undisturbed habitats. More data on marine introductions from other tropical areas are therefore needed to confirm or deny the Queensland Port study's proposed paradigm of resistance by tropical marine communities to marine pest invasions. However, many tropical regions are remote, with few taxonomists and resources available to accurately document their native biota and to recognize nonindigenous species unless populations reach plague proportions. For example, it is not yet clear how much, if any, successful colonization and spread of nonindigenous fouling mussels has occurred beyond the many artificial, heavily disturbed, and polluted habitats of major tropical Asian ports such as Singapore, Hong Kong, Manila, and Venkitsalam.

On the other hand, further monitoring of Australia's northern ports (several more are nearing completion, including Gove and Cairns), together with a nonindigenous species study of the harbors at Guam (Paulay, Kirkendale, Lambert, and Starmer, unpubl. data) and surveys proposed for Lautoka and Suva Harbors in Fiji, should all yield valuable information. Apart from bleaching stresses due to global warming, coral reefs near most centers of dense population are being heavily affected by other anthropogenic stressors, including sedimentation, overfishing, and eutrophication (e.g., Wilkinson 1998). Enclosed ports, estuarine harbors, and artificial marinas offer nonindigenous species readily available "vacant ground" due to human activities. In the same vein, stressed and overfished coral reef communities with few herbivores and high sedimentation and nutrient levels must be considered to be far more prone to colonization by nonindigenous macrophytes or filter-feeding fouling bivalves than undisturbed, healthy reef systems.

CONCLUSIONS

The risk assessment study of some of the major Queensland ports hypothesized that nonindigenous species are less able to survive and develop sustainable populations in "well-connected high diversity" tropical marine communities (such as those in and near the central Indo-West Pacific) than in ports located in biogeographically isolated areas in both temperate and tropical areas. This hypothesis has been largely supported by recent field surveys of some of these ports and the recent surveys of Hawai'i where a large number of nonindigenous species has been confirmed. There is also evidence that relatively undisturbed tropical communities are less susceptible to a nonindigenous species becoming a pest with ecologically damaging, noxious characteristics (i.e., by reaching plague proportions, usurping and changing habitats, and causing loss of diversity, etc.). This observation needs to be further tested by undertaking additional surveys of ports and adjacent areas in the Indo-West Pacific.

It also seems that artificial, disturbed, and/or polluted tropical habitats can be as susceptible to establishment of fouling nonindigenous species as those in temperate areas. Examples from the Tropics include the recent colonization of the black-striped false mussel in the Darwin marina, and other nonindigenous species that have colonized various harbor areas in Singapore and Hong Kong. In Hawai'i, polluted inshore reefs are susceptible to introduced macrophyte colonization, and with it smothering of reefal communities (Smith et al. 2002).

However, what is not yet clear is the ability of nonindigenous species that have become established in disturbed and/or polluted tropical harbors to colonize nearby open coastal habitats. Although this report has concentrated on the macrobiota, there is also the transfer of nonindigenous dinoflagellates by ballast water. It should be noted that tropical areas already have their own "suite" of widely dispersed toxic species that can cause damaging red tides at any place/time where human-induced or natural eutrophic conditions arise (Hallegraeff and Bolch 1992, Choo 1994, Hallegraeff 1998).

Finally it should be recognized that many taxonomic problems in the Indo-Pacific biota remain to be clarified, with some genera having many closely related and similar morphological species. Thus it is essential to lodge voucher specimens in a recognized institution that can then be later checked for taxonomic clarification if necessary. It is hoped that as more baseline studies are undertaken the natural ranges of species can be determined and the status of the cryptogenic species can be clarified. Modern techniques such as DNA analyses can be used to confirm whether isolated populations of species are genetically similar, and in some cases fossil, historical, and regional records can be used to confirm that a species is actually introduced and not a previously unrecorded native that has undergone a local population increase.

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