APPENDIX 1: Introduced marine species risk assessment - background information and rationale

A1.1 Definitions, Characteristics and Categorisation of Introduced Marine Species

"The less a science has advanced the more its terminology tends to rest upon uncritical assumptions of mutual understanding" (Quine 1946, in Carlton 2002).

Research, understanding and modelling of marine invasions is an immature, emerging science and its terminology is continuing to change and evolve. As yet, there is no convenient or widely used glossary that provides an integrated set of consistent, logical definitions based on fully understood processes. We therefore use terms that have been defined, discussed or followed by various publications, including Carlton (1985, 1987, 1996), Cohen and Carlton (1995), Hilliard *et al*. (1997), Hutchings *et al*. (2002), Williamson *et al*. (2002).

The terms non-native species and non-indigenous species (NIS) are more precise and preferable to vernacular and ambiguous terms such as alien, adventive, exotic, foreign, invader, weedy or feral [1] species. All marine species invasions are international, and successful efforts to curb and combat them require the collaboration, mutual understanding and willing cooperation of many marine scientists, advisers, bureaucrats and senior politicians whose first language is not English. For this reason alone it would be useful to avoid a plethora of interchangeable terms. Given the ambiguities and various cultural nuances associated with terms such 'alien', 'foreign', 'exotic' etc, it is also perhaps surprising that definitions issued by IUCN, APEC MRCWG and other international bodies continue to promulgate their usage. Warnings placed in documents destined for wide international circulation, such as "*It should also be noted that several terms are used interchangeably. These include: mariculture and aquaculture; invasive alien species and introduced pests; exotic, alien and introduced. Acknowledgment of this is important for clarity of this report*" are not particularly helpful.

A cryptogenic species is "*neither demonstratively native nor introduced"* (Cohen and Carlton 1995, Carlton 1996). Many of the widespread and so-called 'cosmopolitan species' are cryptogenic, as their original natural distributions have been blurred by centuries of transfer via sail ships, canoes, canal building etc. In fact in some regions many historical introductions had been assumed part of the native marine community until recent studies invoked doubt. Examples include some of the cosmopolitan foulers and wood-borers, such as the infamous bivalve 'shipworm' (*Teredo navalis*), the ship barnacle (*Balanus amphitrite*) and both the blue and brown mussels (*Mytilus* spp. complex; *Perna perna*)(Leppakoski *et al.* 2002, Zaitsev and Ozturk 2001, Dr F. Fernandes, pers comm.).

The terms introduction and introduced species are still causing confusion as they are often poorly defined. For example, the definitions in the recent APEC MRCWG glossary ("*an introduced species is a marine species that's movement has been assisted by human activities to an area outside its range*"; "*an introduction/translocation is the human-assisted movement of an animal to an area outside its natural range*"; in Williamson *et al*. 2002) are inconsistent (plants and protists are ignored), ambiguous and essentially misleading. They offer no hint of the distinction that needs to be made between human-mediated transfers (translocation) of organisms or their propagules, and the potential establishment of a self-reproducing population because of such transfer. Other definitions acknowledge this need, eg. '*an introduced marine species is one which, through human activity, has established a self-reproducing population in a natural or semi-natural habitat outside its native range*.' This definition places the introduction at the end of a long chain of events, by not separating an initial pioneering population from an established (acclimated/naturalised) one.

---

[1] A feral marine species is best associated with a NIS originally imported by the aquaculture or aquarium trade that has since escaped to establish a self-maintaining population 'in the wild'. This provides a meaning similar to that used for domesticated terrestrial animals, since many aquaculture and aquarium species undergo some forms of selective breeding for improved husbandry.

In an attempt to avoid this ambiguity and cover transitory introductions that have occurred from time to time in Australia and elsewhere, Hilliard *et al.* (1997) expanded on Carlton (1985) to define an introduced marine species as: *"a species which, following human-mediated transfer, goes on to form at least a transitory population that is recorded within a region beyond its native range. An introduced marine species is not established, and may fail to achieve a viable long term population owing to inhibition of a key life-cycle stage by local factor/s that affect some aspect of growth, reproduction, settlement or recruitment. In such cases only repeated inoculations may enable the continued (or sporadic) presence of a detectable population*.

Cohen and Carlton's (1995) description of an established population ("a*n introduced species that is present and reproducing in the wild, and whose numbers, age-structure, distribution and persistence over time suggest that they will continue to be present - barring eradication efforts or a major natural catastrophic event*") was modified by Hilliard *et al*. (1997) to cover areas where 'a major natural catastrophic event' is not particularly rare:

An established population of an introduced species is one that:
- *exhibits a mature age-structure and apparently viable size;*
- *has persisted by natural means for several years, including at least one natural climactic event or extrema (eg. cyclone, flood, severe winter, etc); and*
- *appears capable of spreading by natural and/or human-mediated means.*

Invasive species form a *subset* of established introduced species, although increasing *ad hoc* use of this term to convey a sense of impact and urgency for virtually any introduction, historic or recent, has diluted its meaning (Carlton 2002).

The APEC MRCWG description of an invasive species in Williamson *et al*. (2002) is taken directly from IUCN (2000): "*an alien species that becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity*". This definition is problematic as it invokes unclear and indistinct concepts (Carlton 2002).

It is more useful to define an invasive species as: *an established introduction which has good dispersal characteristics, tolerates a range of localised environmental conditions, forms a common component of the habitats and communities into which it spreads and is, or threatens, colonising a wide geographical area* (eg. Thomson 1991, Hilliard *et al.* 1997, Ruiz *et al*. 1997). It can also be argued that a truly invasive species is one which spreads without any form of human assistance into natural or at least semi-natural areas that are not significantly disturbed or 'vacant' due to previous natural or human causes. As summarised by Hutchings *et al*. (2002), an invasive marine species is typically (but not always):

- Common (= relatively abundant and widespread within their native range);
- Pioneering (= among the first to colonise or utilise disturbed and 'vacant' habitats in both its native and introduced regions; includes most port and harbour foulers);
- Tolerant (= can endure a broad range of physical conditions including temperature, salinity, substrate type and pollutants, and often having a tough or quiescent life-cycle stage well-adapted for surviving extreme conditions as well as dispersal);
- Generalist (= eg. ingests a range of food by filtering, deposit feeding or scavenging); and
- Competitive (= out-competes/overwhelms native taxa by shading, smothering, altering substrates, predating or excessively filtering the water column; achieved by developing large populations via better reproduction, recruitment, growth and/or survival rates, including relative impunity to local predators, parasites and diseases).

Whether or not an invasive species becomes labelled a 'nuisance species' (USA/ Canada), 'marine pest' (Australia/New Zealand), 'harmful species' (IMO) or 'alien invader' (IUCN) depends on its location and the perceived type and extent of its known or suspected ecological or socioeconomic effects. As with its terrestrial counterparts, an invasive marine species typically attains such labels by sheer density of numbers, competitive prowess, rate of spread and/or noxious trait.

'Invader', 'pest', 'nuisance' and 'harmful' species are not based on any agreed scientific definitions but stem from terminology used in the lists and guidelines that were compiled in the 1990s for the various emerging policies of governments and international agencies. As Carlton (2002) notes, "*the concepts and thus words used to describe non-native species vary among countries and among scientists, and in the near future show no clear indication of achieving either intra-national or international uniformity (or understanding)*".

For convenience this report follows the AIMPAC/ANZECC/CSIRO term marine pest, which is defined in the APEC MRCWG glossary as "*a non-indigenous species that threatens human health, economic or environmental values*" (Williamson *et al*. 2002). This definition is neither explicit nor particularly useful as it invokes unclear processes and features (Carlton 2002). We prefer the following definition, which draws from Hilliard *et al.* (1997):

An introduced marine species typically attains the status of a 'pest' (= nuisance species) if it has been reported to have demonstrably:

- Reduced native biodiversity via competition, habitat alteration or diverting food-chains;
- Infected, parasitised or otherwise directly or indirectly damaged a commercial or recreationally important finfish or shellfish stock;
- Caused gross fouling of hulls, seawater intakes, jetty piles, buoys, mariculture nets, etc;
- Caused public health risks directly by infection (eg. viruses or bacteria such as *Vibrio* or *Clostridium*) or indirectly via release of toxins that disrupt mariculture or aquaculture operations (eg. toxic dinoflagellate blooms); or
- Degraded a recognised public amenity or aesthetic value.

Terms such as suspected pest can be used where the apparent, supposed or deduced impacts have not been described by published study or government report.

It has been suggested that all invasive species which are defined by a 'spread' criterion must, *ipso facto*, be exerting ecological impacts (in Carlton 2002), in which case all invasive species would fall under the 'pest-nuisance-harmful' category. However in the Eastern Mediterranean and Hawaii there are many invading species which have not been associated with any native biodiversity loss or other ecological effect, principally because they appear to have been taking up 'vacant' Eltonian niches/ecological space (eg. Coles and Eldredge 2002, Leppakoski *et al*. 2002). It therefore seems prudent to allow the division, at least for the time being.

Vectors: these are the physical means or agents by which a species is transferred. Ballast water, ships' hulls and the movements of commercial oysters and baitfish in the aquaculture industry are examples. The particular routes taken by these vectors are sometimes termed pathways. Evaluating the potential vectors and their routes is an integral part of the risk assessment process. It is worth noting that routes can be divided into primary and secondary categories. Primary routes can transfer NIS across significant regional barriers (trans-oceanic and intercontinental pathways), while secondary routes help transfer and disperse NIS between points within and between neighbouring regions (ie. the pathways of domestic or local 'hub' traffic).

The term inoculation means the release, discharge or dislodgment of viable organisms in sufficient numbers and/or frequencies that provide more than a negligible or low chance of successfully forming a pioneer stock (eg. Hilliard *et al.* 1997, Hayes 1997, Hewitt and Hayes 2002). Although it is theoretically possible for a single incident involving release of one small colony or two individuals to cause a new population in a novel environment, the chances would be very small. A significant exception comprises the transfer of a handful of mature adults of a sessile taxa into an artificial harbour or other semi-enclosed quiescent area where levels of filter-feeding and predation are low, as these may release thousands or millions of gametes if spawning cues are present. Completing fertilisation, planktonic growth and settlement stages would be far more difficult, however, in the case of the open and tidally flushed waters at Ashmore Reef and Cartier Island.

A1.2 Risk Assessment Methods

Risk is a measure of the likelihood of an event and magnitude of its consequences, and can be estimated by qualitative, semi-quantitative or quantitative means, depending on the type and amount of available information and completeness of the models of the activity under investigation.

In a typical quantitative risk assessment, risk is some measured social-economic consequence (end-point) of an identified hazard, multiplied by the probability of that hazard occurring. Careful identification of the hazard and evaluation of its possible consequences is required, via a detailed hazard analysis, as the first step of the risk assessment process. For example, the pertinent end-points for quantifying the risk of an explosion inside a petrochemical plant would be determined by identifying each hazardous site in the plant, the types and combinations of equipment failures/human errors that could cause an explosion at each of these points, the potential circumstances causing their coincidence, and the number of deaths and injuries each particular event would cause (often measured in terms of the dollar costs associated with compensation payments, legal costs, rebuilding, lost production, lost marketing, etc). Thus identification of the hazards and their consequences (end-point) is a critical step of any risk assessment. A quantitative risk assessment will also provide measures of certainty of the calculated risks.

In the case of assessing the risk from human-mediated introductions of marine NIS, attempting a conventional quantitative risk assessment is impractical as invasion models remain incomplete and there are rapidly increasing uncertainties with each step of the process (eg. from vessel uptake/infection, voyage survival, release/inoculation and survival in new environment, to population establishment, spread, outcomes and impacts; eg. Hayes 1997, Hilliard and Raaymakers 1997, Hayes and Hewitt 2000, Hewitt and Hayes 2002, URS 2002).

A quantitative risk assessment is only possible if (a) the consequence of the NIS transfers (end point) is simplified to minimise the number of steps and uncertainties, (b) each NIS is identified and assessed individually (ie. a targeted species approach), and (c) key physical processes and features dictating the chances of uptake, survival and release are known for each route, species and life cycle stage involved in the introduction process.

With respect to (a), if the end-point is 'the establishment of a NIS population at the site of interest', then the risk needs to be expressed in terms of likelihood of establishment, whereas if the end-point is some subsequent effect such as the displacement of local species (= loss of native biodiversity), then the risk must be defined as the likelihood of this ecological damage resulting from the introduction and establishment of a NIS. The former end-point is more simple and carries the implicit assumption that establishment of any NIS is unwanted. Even this is difficult to predict with any certainty, so the simplest end-point would be 'inoculation of a NIS into a port where its life cycle stages are deemed likely to tolerate local conditions'.

The latter end-point assumes that merely the opportunity for a NIS to survive, grow and reproduce is the undesirable factor. While this might be an acceptable management objective for a remote, near pristine and unique nature Reserve located far from any regularly used berths, moorings or anchorages, it is impractical for multi-use waters within or near ports, marinas or natural harbours. In these cases, it is more practical to target a subset of NIS, with the assessed taxa comprising either known or suspected pest species (and which may also act as surrogates for unknown risk taxa; eg. Hewitt and Hayes 2002). Constraining the risk assessment to a small subset of the total available NIS also makes the task of acquiring sufficient reliable data on the pertinent environmental tolerance ranges for the principal life-cycle stages of each species more achievable, although this can still be a difficult, time-consuming and expensive process for some species.

Use of the simple 'inoculum end-point' applied to a short-list of target species is the approach taken by AQIS's Decision Support System (DSS) that commenced operation for assessing the risk of voyage-specific ballast water discharges during 2001. The DSS assesses the likelihood that a particular discharge will cause an inoculation of one or more of twelve targeted species at a port where they may be able to survive (Hayes and Hewitt 1998, Colgan 1999, Hewitt and Hayes 2002) [2]. These species are the twelve contained in the AIMPAC 'target' list and which are already established in Australia (the system was originally intended to help reduce the spread of these species within Australia by domestic shipping; C. Hewitt pers. comm.).

Following the Darwin black-striped mussel incursion, and in response to criticism of using a targeted species approach for vessels arriving with a wide range of untargeted species from overseas ports (many were questioning the value of a system that focuses on 'bolted horses'; eg. Hillman 1999), a Joint SCC/SCFA National Taskforce on the Prevention and Management of Marine Pest Incursions was established. This taskforce finalised a 'trigger list' of additional potential pests in 2000, while CSIRO-CRIMP compiled a list of predicted 'next pests' that was released in 2002 (Gollasch 2002a, Williamson *et al.* 2002). The two lists contain species deemed to be of high risk but not yet detected in Australia (see Table 5 in main report), and whose impacts reported elsewhere warrant their treatment as suspected pests. The lists are also designed to help CCIMPE evaluate the speed and scale of an emergency response following discovery of a new incursion. Some of the listed species are also planned to be added to the DSS at a future date. As described in the APEC-MRCWG report (Williamson *et al.* 2002), the four criteria used to justify inclusion of species onto the trigger and next pest lists are:

1. A demonstrable invasive history.
2. One or more relevant transport vectors are still operating (including hull fouling):
3. A demonstrable impact in either their native or invaded ranges on economy, environment, human health and/or amenity.
4. Predicted to have potential major impacts in Australia, as inferred from overseas data and the characteristics of Australian marine environments and their communities.

Removal of a species from the trigger or next pest lists requires reliable empirical scientific data showing that (a) impacts reported overseas are less than first thought, (b) potential impacts in Australia would probably be less than previously thought, or (c) the species becomes widely distributed in Australia.

The following sections provide a hazard analysis that backgrounds the vectors and routes, the species involved and the consequences of establishment, with a focus on hull fouling and marine introductions in tropical regions.

A1.3 Relative Importance of the Ballast Water, Hull Fouling and Debris Vectors

Each year some 10,000 ships arriving from over 600 overseas ports discharge approximately 150 million tonnes of ballast water into 64 international ports and export terminals around Australia, and a further 30 million tonnes is discharged by Australia's domestic shipping activities (AQIS 1998).

Black *et al.* (1994) reviewed the contribution of the petroleum industry to these discharges and found that the proportion of the total tonnage discharged by crude oil tankers was small (<4%), with their voyage routes also posing less risk than ships engaged other trading routes

[2] The DSS can use one of five levels of assessment, with the level used to assess a particular vessel determined by the available data. The more quantitative 'upper' levels require detailed data about the ballast water source point (typically lacking for most overseas points).The 'lower' levels use semi-quantitative methods including an environmental matching component (temperature and salinity range) when key data are absent, a typical situation for overseas arrivals. The DSS started in July 2001 and in the second half of 2002 was using its lower levels to assess the intended ballast water discharges of some 10-12% of all merchant ship arrivals from overseas ports (T. Snell, AQIS, pers comm.).

(particularly bulk carriers visiting southern Australian ports from Japan, Korea and north-east China; Hilliard *et al.*1997). In the case of the Ashmore Reef and Cartier Island region, crude oil tankers represent some 7-10% of the local traffic (Tables 7, 8 of main text) and the closest oil export terminal (Jabiru) is more than 120 km to the east. Compared with the tankers that export produced crude, the deballasting requirements of the various drilling rigs, platforms, FSCPs and support vessels involved in the petroleum exploration and production activities are negligible or zero.

Importance of Ballast Water versus Hull Fouling and other Vectors

Pollard and Hutchings (1990) listed 57 marine species introduced to Australia and noted that only 14 of these (25%) were probably introduced by ballast water, with hull fouling and aquaculture being the most common vectors. Current estimates of the total number of NIS in Australian waters range between 210-250, with some 30-40 of these probably introduced via ballast water (eg. Thresher 1998, Hilliard 1999, Hewitt and Martin 2001, Hutchings *et al.* 2002).

The recent data for Australia, New Zealand and Hawaii continue to suggest that the proportion of ballast water-mediated introductions in recent decades (5-20%) does not appear to have altered compared to other vectors such as hull fouling, aquaculture and canals (eg. Hines 1995, Coles *et al*. 1999ab, AMOG 2002, Hutchings *et al*. 2002, URS 2002, Williamson *et al*. 2002). The situation in Europe and US is less clear. For example, AMOG (2002) reviewed the German port hull surveys made by Gollasch and others, which indicate continuance of hull fouling as the most common vector. However, Minchin and Gollasch (2002) report that, of the total number of introductions first recorded in Europe during 1998-2000, the most frequent were ascribed to ballast water (~14.5%), with hull fouling (~9%) in second place.

The role and importance of hull fouling in the continental United States has been less studied, particularly when compared to the situation in Hawaii (eg. Coles and Eldredge 2002). As Holm and Everett (2002) note, of particular current interest in the US mainland is the frequency with which hull-fouling mediated introductions are occurring relative to other transport mechanisms, including the role of hull fouling in 'secondary transfers' and dispersal (ie. intra-coastal routes along the various US coasts and waterways) versus 'primary transfers' (ie. inter-coastal routes from overseas ports).

Types of Hull Fouling

The types of hull-fouling risks posed by merchant ships and warships arriving in Australian ports have been examined and discussed by Rainer (1995), Walters (1996), Coutts (1999), and URS (2002). AQIS has also commissioned a series of studies to evaluate this vector and identify practical control measures for commercial and private vessels (AMOG 2002).

Heavily fouled vessels may carry up to 5 kg of material per square metre, which can amount to some 60 tonnes for average-size vessels (Walters 1996). Over 90 metric tonnes of fouling material was brought to New Zealand on the hull of a small Russian vessel which previously had been laid up for several years in the Black Sea (Hay, in AMOG 2002). Thus the risk of hull fouling organisms being introduced via drilling rigs, barges and platforms towed into Australian waters for petroleum exploration or dredging purposes are potentially far greater than that by normal ships as the former (as well as RAN units) are often anchored or laid up for relatively long periods. Some are also not painted with efficient organotin-containing anti-foulings owing to TBT-ban policies of their owners, the Flag State and/or local regulations applying to previous deployment in an environmentally sensitive area (URS 2002).

Effect of Lay-Ups and Similar Idle Periods

Vessels that have been poorly maintained and/or undergone significant lay-up periods prior to a relatively slow passage or tow to Australian waters (such as SIEVS, barges, drilling rigs, tugs, support vessels or mothballed naval units) markedly enhance the risk of introductions by hull fouling species. SIEVs are unlikely to have any fresh anti-fouling coatings, and even recently applied self-polishing and ablative anti-fouling coatings do not work effectively in the absence of regular water turbulence (eg. Rainer 1995, AMOG 2002, URS 2002).

There is no doubt that the post-war development and movements of semi-submersible and jack-up drilling platforms provided a new vector for marine introductions in the Indo-Pacific region. One drilling platform that arrived in New Zealand in 1975 following a long, staged tow from Japan was found to be heavily fouled by a wide variety of biota, including filamentous green and red algae species, eight barnacle species of north-west and west Pacific origins and representing three genera (*Tetraclita*, *Balanus* and *Megabalanus*), Japanese grapsid crabs (*Plagusia depressa tuberculata*) and sergeant-major fish (*Abudefduf saxatilis*) from the Solomon Islands (Foster and William in AMOG 2002). Reef-building corals can also colonise oil platforms and other long-standing structures if located in areas 'down-current' of extensive reef tracts, such as parts of the Gulf of Mexico (Bright *et al.* 1994).

After arriving from a distant port any vessel or platform which lies inactive for an extended period at a port, anchorage or well-site provides its fouling species the opportunity to mature and spawn, with nearby wharf piles and breakwaters in ports providing convenient settlement areas. However the introduction risks associated with such arrivals are easy to avoid provided the agencies regulating the offshore petroleum and dredging industries notify the chartering company or port authority of the need to ensure that all wetted surfaces of these vessels are cleaned (and certified as such) prior to their departure for Australia.

Any in-water hull cleaning, propeller polishing or other maintenance operation applied to a fouled commercial or recreational vessel increases the chance of introducing fouling species, since the crushing of many invertebrate species can release eggs and sperm, whilst those dislodged partially intact fall to the seafloor (Walters 1996). Some of the latter may survive, such as colonial forms if swept into rocky or stony areas that permit reattachment, division, and eventual reproduction (Hilliard *et al.* 1997, AMOG 2002).

Role of Fouling on Recreational Vessels and Marine Debris

Floerl and Ingliss (2001) have been examining the role of recreational vessels moored at three Queensland marinas (Cairns, Townsville and Airlie Beach) in the secondary spread of introduced species along tropical coasts by hull fouling. Their work has shown that, contrary to the belief that modern antifouling coatings prevent hull fouling on recreational vessels, owners of yachts and launches tend not to abide to manufacturers' recommendations for annual slipping and repainting, but undertake a two year cycle in which the steady build-up of fouling species during the second year is removed by in-water cleaning. Hutchings *et al.* (2002) have also noted that in-water cleaning of cruising and domestic yachts is not uncommon on the north and eastern coasts. AMOG (2002) provides a contemporary and detailed review of both historical and recent facets of the hull-fouling vector.

Far less has been reported on marine debris as a vector for dispersing NIS, with the significance of discarded fishing gear and floating rubbish, particularly plastics, becoming the focus of attention only recently (eg. Gregory 1998, Barnes 2002). Willoughby *et al.* (1997) have described the sources and impacts of beach litter to wildlife and coastal communities in the Indonesian archipelago, while Kiessling and Hamilton (2001) describe recent results of a ongoing program that has been examining the type, quantities, likely sources and impacts of marine debris that drift onto shorelines near Cape Arnhem from the Arafura Sea and Gulf of Carpentaria.

Around 60% of the material surveyed was plastic, with the greatest proportion of plastics and fishing nets originating from Indonesian fishing vessels and Australian prawn trawlers (although source of Korean and Taiwanese manufactured nets was unclear). Kiessling and Hamilton (2001) acknowledged the vector potential of the marine debris but did not apparently identify, record or take samples of the biota fouling the monitored litter.

A1.4 Types of Hull Fouling Biota

As with ships, drilling rigs, barges and floating or fixed platforms, the underwater surfaces of fishing vessels, patrol boats and SIEVs offer various underwater structures and apertures that provide shelter from turbulent flow, albeit to a more limited degree. Appendages such as fins, bilge keels, strakes, rudder pins, thruster casings and propeller bosses, as well as intakes, outlets, sea chests and their gratings, are more conducive to fouling than smooth plating or planking because they provide shelter from turbulent flow, may not be coated with a fouling protector or, if coated, the protection is prone to damage or flaking. Wherever the fouling protection coating is old, damaged or absent, surfaces and crevices can be rapidly occupied by a range of fouling plants and animals. The following types of biota are the most common (see AMOG 2002 for detailed review):

(a) Slime builders: these comprise a range of heterotrophic bacteria, cyanobacteria, diatoms and other unicellular algae that form the 'pioneering' biofilms and slimes that can reduce the anti-fouling properties of the hull coating. The biofilms will colonise antifouling paints as they are relatively resistant to most toxicants (including organotins), with diatom biofilms producing distinct brown and gold-brown hues on surfaces coated with TBT paints.

(b) Sessile forms. These include the typical fouling species such as filamentous, thalloid and turfing green algae (typically *Enteromorpha* spp.), brown algae (typically *Ectocarpus* spp.) and occasionally red algae, plus hydroids, tube building worms, barnacles, bivalve molluscs, bryozoans (lace corals) and ascidians (sea squirts). These forms can adhere strongly, grow quickly and reach sexual maturity before their eventual dislodgment due to size-induced drag, hull cleaning or natural senescence. A range of other sessile species, including more foliaceous green and brown seaweeds as well as sponges, sea anemones, soft corals and hard corals, can also develop on surfaces subjected to long periods of relatively uninterrupted static immersion such as drilling rigs, barges, floating docks or decommissioned vessels (eg. Bright *et al.* 1994, Hay and Dodgshun 1997, DeFelice 1999, AMOG 2002).

(c) Mobile forms. These include small crustaceans including caprellid, corophid and gammarid amphipods, isopods (sea slaters), small crabs, gastropod molluscs, gobies and other fish. They have typically been found to have avoided dislodgment by:

- clinging to other fouling species and/or the less turbulent parts of the hull
- grasping or nestling amongst established algae and encrusting species (includes the amphipods, sea slugs and nudibranchs); or
- sheltering within empty barnacle testes, small apertures and pipe-work (includes crabs, gobies and other fish).

(d) Parasites and pathogens. These have a commensal, parasitic or infective relationship with attached organisms, ie. they occur intimately within another fouling organism, and include viral and bacterial pathogens as well as a range of micro-crustaceans and other parasites. They can also be present in slimes.

A1.5 Hazard and Consequences

Overview

As noted in Section A1.2, it is necessary to examine the hazards and consequences to help identify an appropriate end-point that is relevant to managers and practical for risk assessment.

Of the large numbers of introduced species now documented for the coastal waters of Australasia, Europe and North America, 5-15% have achieved a pest status in most regions (eg. Ruiz *et al*. 1997, Leppakoski *et al.* 2002, Williamson *et al.* 2002). Many have now spread far from the ports where they were first introduced, and there are no effective ways to eradicate established populations except in localised sites amenable to closure and intensive management (eg. Pyne 1999, Culver and Kuris, 2000).

Present effects on ecosystems, biodiversity, fishery and wildlife stocks range from basin-wide severe impacts in temperate areas (eg. North American comb jellyfish in Black Sea and European zebra mussel across U.S. watersheds), to restricted and as yet unclear effects in tropical regions. The latter includes black-striped mussels (*Mytilopsis sallei*) and Asian date mussels (*Musculista senhousia*) colonising disturbed and polluted harbour habitats in Singapore, Hong Kong, Manila, Mumbai and Vizakhapatnam, and red macroalgae (*Acanthophora spicifera, Hypnea musciformis*) colonising polluted and disturbed coral reefs in Kaneohe Bay, Hawaii (Coles and Eldredge 2002, Hutchings *et al*. 2002, URS in prep.)

Among some of the infamous introductions of the previous century, several did not spread or show signs of their invasive prowess and harmful effects in initial years and even decades, while others have undergone 'boom-bust' cycles (eg. Chinese mitten crab *Eriocheir sinensis* in parts of Europe). Reasons why introductions can take time to start spreading include the processes of local adaptation/gene selection, the appearance of a new vector allowing spread from a previously isolated location, a change to the local pollution and habitat conditions, and global warming. The boom-bust phenomena have been related to short-term climate variables such as winter temperature and rainfall intensities (in Leppäkoski *et al*. 2002).

There is also no reliable method to predict, divide or even scale 'harmless' from 'harmful' NIS without clear-cut quantifiable definitions, good data and reliable invasion models (all currently lacking; Carlton 2002). It is therefore not particularly useful to adopt such a dualist approach other than for convenient administrative, management or political purposes. A precautionary rather than dichotomous approach is also more suited for managing Reserves and other protected areas that are gazetted for conservation and biodiversity protection purposes. Thus it is better for a hazard analysis and qualitative risk assessment to simply identify which NIS have known, suspected or apparently no harmful credentials, using the various regional and global lists compiled in Australia, Europe and North America (eg. Gollasch 2002ab, Williamson *et al*. 2002, URS in prep.).

Tropical versus Temperate Marine Introductions in Australia

The majority of marine introductions in Australia have occurred predominantly in the temperate coastal waters of the southeast, plus parts of the southern and southwestern coasts. Approximately twenty of these species, including several toxic dinoflagellates, are marine pests that have been causing significant ecological and/or economic effects in various ports, bays and estuaries in Victoria, Tasmania and NSW, including impacts to oyster culture and coastal abalone fisheries, changed benthic habitats and reduced local biodiversity. Several pests have spread throughout large bays and/or along open coasts (eg. Japanese wakame kelp (*Undaria*), Northern Pacific seastar (*Asterias amurensis*), several toxic dinoflagellates, European green crab (*Carcinus maenas*), and New Zealand screw shells (*Maoricolpus roseus*). These plus other taxa were the twelve pests targeted by AIMPAC and used by the DSS as part of the effort to reduce their rate of spread in Australia, and other known or potential pests have since been listed (Table 5 in main report). The native ranges of these known or suspected pests comprise Europe, Mediterranean Sea, New Zealand, north-west Pacific, north-west Atlantic and Caribbean, with others remaining cryptogenic.

Establishment of Marine Pest Species in Tropical Regions

Both the number and pest credentials of established NIS decline as one heads northwards into subtropical then tropical waters on both sides of Australia (Hilliard *et al*. 1997, Hoedt *et al*. 2000, Hutchings *et al*. 2002, Ruiz and Hewitt 2002, Table 5 in main report). Although data on the types and distribution of invasive species in tropical regions are relatively few, there is an emerging pattern that, apart from polluted harbours prone to colonisation by nuisance fouling species and the relatively low diversity habitats in the biogeographically isolated Hawaii islands, the biological communities of coral reefs and other tropical habitats in the Indo-West Pacific and Caribbean regions have been far less prone to marine invasions and their ecological effects than those of temperate regions (Hilliard *et al*. 1997, Hilliard 1999, Coles and Eldredge 2002, Hutchings *et al.* 2002, Ruiz and Hewitt 2002).

Transfers of marine species from SE Asia into northern Australia are not considered to provide a major risk for two reasons. Many share the same natural range, while those which are endemic to the Indo-Malay / southern Philippine/ Papua New Guinea 'triangle' of megadiversity (ie. absent from north Australia) have had plenty of time and opportunity to extend their range southward by natural and human-mediated mechanisms. These include the Indonesian 'through-flow' that helps generate the Leeuwin Current, plus several hundred years of human visits for trepang, trochus and shark fishing using craft similar to the traditional Indonesian sailing vessels that continue to visit the Ashmore Reef.

While there are no significant biogeographical barriers between the waters of Indonesia – Papua-New Guinea and northern Australia, the relatively small latitudinal shift out of the intertropical convergence zone into the Timor, Arafura and Coral Seas results in a marked reduction in annual rainfall as well as generation of cyclones due to the coriolis effect. The significant changes in rainfall patterns, cloud cover, wind strengths and insolation/evaporation rates, together with a concomitant drop in the density of reefal and brackish coastal habitats in the Timor Sea and its much larger tidal ranges, explain why many marine taxa endemic in the more humid equatorial 'triangle of megadiversity' have not managed to radiate into north-western Australia following the glacial sea level minima of the Pleistocene (Hilliard *et al.* 1997).

The same cannot be said, however, for several invasive fouling species now present in many Asian harbours, including ports where SIEVs may have originated or spent long periods (eg. Vizakhapatnam, Colombo, Singapore, Hong Kong, Jakarta and Surabaya). Following the discovery of these taxa on the hulls of various apprehended vessels arriving at Darwin and Cairns, increasing attention is now being paid to these fouling bivalve mussels, serpulid tube worms and barnacles, as some have been introduced into the Indo-Pacific from the Caribbean (via a Pacific island 'stepping stone' process), while others have spread south from temperate and subtropical Asia into tropical waters via a 'port-hopping' and acclimation process that may be linked to rapid development of coastal aquaculture along Asian coasts in the last 50 years.

The latter taxa includes the Asian date mussel (*Musculista senhousia*), which can be an aggressive invader of disturbed estuarine and brackish harbour environments where it forms dense mats that trap sediments and smother other organisms. Its original North-West Pacific range appears to have been from the southern margin of Siberia to Taiwan and northern Philippines, but its present-day populations demonstrate remarkable thermal tolerance as they now occur in Singapore and a range of estuarine ports and harbours in the central and southern Philippines, the Mediterranean, north-west America, New Zealand, Victoria, New South Wales and the Swan-Canning system at Perth (URS 2002, URS in prep.). Its propensity for estuarine areas implies a low risk for the Ashmore Reef and Cartier Island Reserves.

Similarly, the apparent thermal, salinity and habitat preferences of other Asian bivalves with pest potential, such as *Potamocorbula amurensis* (the Asian clam), *Theora lubrica* (native to the Pacific coast of Asia, now present in northern New Zealand) and *Crassostrea gigas* (the Pacific oyster), indicate at best only a moderate chance of establishing a persistent population in northern Australia compared to subtropical and temperate areas further south (Hilliard *et al.* 1997, URS 2002).

Compared to southern Australia, introductions to Australia's tropical ports have been fewer and, with the exception of the black-striped mussel (*Mytilopsis sallei*) episode in Darwin's lock-gate marinas, less spectacular in terms of causing a substantial socioeconomic impact and response. This fast-growing bivalve rapidly colonises vacant hard substrates and has established a permanent presence in many south and east Asian harbours (including India, Sri Lanka, Singapore, Philippines, Indonesia, southern Japan and China), as it appears to prefer relatively sheltered waters with small tidal movement. It undoubtedly continues to pose a major fouling threat whenever transferred into Australia's coastal waters from an infected Asian port.

Equally significant tropical NIS incursions discovered on the hulls of vessels arriving at Darwin (in terms of the potential to cause a long term economic fouling impact and possible ecological effects) are the Asian green mussel *Perna viridis* and the Caribbean tube worm (*Hydroides sanctaecrucis*). As with *M. sallei*, both species in their native ranges appear to prefer relatively sheltered and mangrove-lined estuarine areas rather than exposed coastal habitats and coral reefs.

The green mussel has been found in Darwin on the hulls of small vessels from Vietnam (1991) and Indonesia (1999), and in Cairns in 2001 on small vessels and barges in Trinity

Inlet (source unclear). The green mussel has yet to establish in either Darwin or Cairns (only a few individuals have been found on individual hulls and derelicts - http://www.env.qld.gov.au/cgi-bin/w3-msql/environment/science/water/msqlwelcome.html?page=marine_pests.html). The fouling tube worm *H. sanctaecrucis* was first recorded in Cairns in 2000, colonising the hull of temporarily laid up RAN units whose anti-fouling coatings were old. The source has remained unclear but the vector is almost certainly hull fouling, possibly via a vessel arriving from Indonesia (= secondary route) or else Panama (= more primary route)(J. Lewis pers. comm.). Substantial numbers have since colonised various artificial surfaces in Trinity Inlet as well as the hulls of many vessels. While *H. sanctaecrucis* has established to the point of merging with the native fouling assemblages on both artificial and natural surfaces, it appears to be a poor competitor and has not yet shown any propensity to overwhelm or displace existing taxa, including its congener *Hydroides elegans* (J. Lewis, pers. comm.).

The apparent invasion resilience displayed by Australia's tropical marine communities and presence of relatively few NIS has been lent support from the results of recent NIS surveys at Dampier, Port Hedland, Darwin, Gove, Weipa, Cairns, Mourilyan, Abbot Point and Hay Point (eg. Hewitt *et al*. 1998, Hoedt *et al*. 2000, Russell and Hewitt 2000, URS-CRC in prep.). That the black-striped mussel incursion at Darwin was restricted to the interior of the lock-gate marinas is also considered significant, including its inability to colonise any natural or piling substrate beyond these artificial harbours despite the high densities and at least two spawning cycles it achieved before discovery and eradication (Hilliard 1999, Russell and Hewitt 2000, Williamson *et al*. 2002).

Reasons for the apparent dearth of marine invasions into tropical Australia, despite the high frequency of vessel movements and relatively large volumes of discharged ballast water, were first listed by Hilliard *et al.* (1997) and recently discussed by Hutchings *et al.* (2002), Eldredge and Coles (2002) and Ruiz and Hewitt (2002). Key reasons include the ballast water sources as well as notable differences between Australia's temperate and tropical marine communities in their degree of biogeographic isolation, endemism, tolerance to physical stresses, and biological 'defence' capability. To confirm emerging patterns and apparent processes, however, more NIS surveys are required for ports and coral reefs in both biogeographically isolated and well-connected tropical regions around the world (Hutchings *et al.* 2002, Coles and Eldredge 2002, Ruiz and Hewitt 2002).

APPENDIX 2: Site information for activities undertaken during the marine NIS survey within the Ashmore Reef National Nature Reserve.

Date	Location	Structure	Activity	Latitude	Longitude	Max. Depth (m)	Sample #
28/05/2002	Inner Lagoon	Wreck 1	Free Dive	-12.23863	122.9792	10.00	-
28/05/2002	Inner Lagoon	Inner Customs Mooring	Free Dive	-12.22063	123.01856	8.00	-
29/05/2002	Inner Lagoon	Four bommies	Scuba	-12.23937	122.98639	10.00	-
29/05/2002	Inner Lagoon	Finger Reef	Scuba	-12.24395	123.00706	10.00	-
29/05/2002	Inner Lagoon	Wreck 1	Scuba	-12.23863	122.9792	10.00	-
29/05/2002	Inner Lagoon	Wreck 2	Scuba	-12.23841	122.97952	10.00	-
29/05/2002	Inner Lagoon	Logs/Bars	Free dive	-12.24073	122.97333	1.0-2.0	-
29/05/2002	Inner Lagoon	Wreck 3	Scuba	-12.22776	123.00959	10.00	-
29/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.21314	123.01774	4.50	-
29/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.2133	123.01748	4.50	-
29/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.21079	123.01487	4.50	-
29/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.21387	123.01921	4.50	-
29/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.21696	123.02068	4.50	-
29/05/2002	Outer mooring	Drift wood	Scrape	-12.23829	122.98562	surface	AR2
29/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR1
30/05/2002	Inner Lagoon	Potential wreck site	Manta tow	-12.21877	123.02042	4.50	-
30/05/2002	Inner Lagoon	Potential wreck site	Scuba	-12.221	123.01897	10.10	AR3
30/05/2002	Inner Lagoon	Inner Customs Mooring	Scuba	-12.22063	123.01856	13.00	AR4
30/05/2002	West Island	Reef flat	Free Dive	-	-	0.70	AR5
31/05/2002	Lagoon channel	Mooring block	Scuba	-12.23888	122.98212	15.50	AR11
31/05/2002	Lagoon channel	Mooring block	Scuba	-12.23777	122.98318	18.00	-
31/05/2002	Lagoon channel	Mooring block	Scuba	-12.23857	122.98437	15.00	AR10
31/05/2002	Lagoon channel	Type III hull	Scuba	-12.23972	122.98458	15.00	AR10
31/05/2002	Lagoon channel	Mooring block	Scuba	-12.23918	122.9848	15.00	AR7
31/05/2002	Lagoon channel	Sea Floor	Grabs	-12.22041	123.01944	15.00	AR6
31/05/2002	Lagoon channel	Drift wood	Scrape	-12.23911	122.98064	Surface	AR8
31/05/2002	Lagoon channel	Sea Floor	Grabs	-12.23907	122.9845	12.70	AR9
31/05/2002	Lagoon channel	Sea Floor	Grabs	-12.2385	122.98413	15.50	AR12
31/05/2002	Lagoon channel	Sea Floor	Grabs	-12.23873	122.9815	18.00	AR13

31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR26
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR16
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR21
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR17
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR22
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR27
31/05/2002	West Island	Beach	Beach Wrack	-	-	-	AR28
1/06/2002	Inner Lagoon	Mooring block	Scuba	-12.23828	122.98255	15.40	AR15
1/06/2002	Inner Lagoon	Mooring block	Scuba	-12.23778	122.98352	16.40	-
1/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.23779	122.98304	15.50	AR14
1/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.23818	122.98252	16.00	AR20
1/06/2002	Inner Lagoon	Inner Customs Mooring	ACV water strainer contents	-	-	0.50	AR23
1/06/2002	Inner Lagoon	Inner Customs Mooring	Floating rubbish	-	-	surface	AR24
2/06/2002	Inner Lagoon	Mooring block	Scuba	-12.238	122.9847	15.00	-
2/06/2002	Inner Lagoon	Mooring block	Scuba	-12.23832	122.98573	14.00	-
2/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.2378	122.98319	2.00	-
2/06/2002	Outer lagoon	Reef crest	Manta tow	-12.23808	122.97987	2.00	-
2/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.21986	122.98561	12.00	-
2/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.23861	122.98543	12.00	-
2/06/2002	Inner Lagoon	Inner Customs Mooring	ACV water strainer contents	-	-	0.50	AR25
2/06/2002	Inner Lagoon	Type II hulls	Free Dive	-	-	1.50	AR29
3/06/2002	Inner Lagoon	Mooring block	Scuba	-12.2378	122.98587	15.00	-
3/06/2002	Inner Lagoon	Mooring block	Not inspected-too deep	-12.22128	123.00978	>18.0	-
3/06/2002	Outer lagoon	Outer mooring	Free Dive	-12.23829	122.98562	10.00	-
3/06/2002	Eastern Lagoon	Reef crest	Manta tow	-12.22087	123.00582	2.00	-
3/06/2002	Eastern Lagoon	Reef crest	Manta tow	-12.19795	123.04083	5.00	-
3/06/2002	Eastern Lagoon	Reef crest	Manta tow	-12.19946	123.04383	6.00	-
3/06/2002	Eastern Lagoon	Reef crest	Manta tow	-12.19002	123.04852	5.00	-
3/06/2002	Eastern Lagoon	Reef crest	Manta tow	-12.19419	123.05681	7.00	-
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.20358	123.06365	2.40	AR34
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.20652	123.05746	5.00	AR39
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.20134	123.04692	7.00	AR33

3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.19214	123.04085	9.00	-
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.22444	122.99992	5.00	AR38
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.22676	122.99768	7.00	AR35
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.23153	122.9962	15.00	AR40
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.23231	122.99095	2.00	AR32
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.23534	122.98896	15.00	AR31
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.2357	122.98579	2.00	AR37
3/06/2002	Eastern Lagoon	Sea Floor	Grabs	-12.23712	122.98237	2.50	AR36
3/06/2002	Inner Lagoon	Bommie	Scuba	-12.23298	122.99925	11.00	-
4/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.23916	122.98013	3.00	-
4/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.24444	122.99263	3.00	-
4/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.24447	122.99972	5.00	-
4/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.24399	123.00744	7.00	-
4/06/2002	Inner Lagoon	Reef crest	Manta tow	-12.23876	123.01292	10.00	-
4/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.23126	123.01164	8.60	AR41
4/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.24207	123.00899	6.00	AR42
4/06/2002	Inner Lagoon	Sea Floor	Grabs	-12.24412	123.0062	11.00	AR43
4/06/2002	Inner Lagoon	Wreck, type II	Free Dive	-12.23902	122.98009	12.00	-
4/06/2002	Inner Lagoon	Wreck, type II	Scuba	-12.23913	122.98019	11.00	AR44
4/06/2002	Grotto	Reef crest	Manta tow	-	-	3.00	-
4/06/2002	Grotto	Reef crest	Free Dive	-	-	6.00	-

APPENDIX 3: Plant invasions and the Ashmore Islands - species and risks

Ian Cowie

N.T. Herbarium, Department of Infrastructure, Planning and Environment, GPO Box 1680 DARWIN NT 0801
Ian.cowie@nt.gov.au

A3.1 Summary and Recommendations

A qualitative survey of non-indigenous plants and native terrestrial vascular plant species was undertaken on the Ashmore islands and Cartier Island during June 2002. Possible invading species from Asia and Australia were identified and vectors for dispersal are discussed. The potential for plant invasions of the Ashmore islands and of Australia from Ashmore are examined.

Thirty species of terrestrial vascular plants were recorded during this current survey, with 39 species recorded over a number of years during this and previous surveys. The parasitic vine *Cuscuta australis* was the only species not previously recorded from the islands. Forty four species have been recorded as drift seeds on the islands' beaches.

Eight non-indigenous plant species are presently known from the Islands. At present, none of the non-indigenous plant species found on the islands can be regarded as a major problem. Of these, *Tribulus cistoides* and *Cenchrus brownii* are well established. Although *Cenchrus ciliaris* is a dominant weed of coastal dunes near Darwin in the NT, it has remained limited in occurrence on West Island. *Cenchrus ciliaris* and *Pennisetum pedicellatum* are found in small populations and should be eliminated from West Island. At present, all except two species of native plant and all of the non-indigenous species (NIS) recorded on the islands are found on the Australian mainland. There is no indication that either of these native species would become serious weeds if introduced to Australia.

The potential impacts of plant species native to the region and dispersing naturally to the islands may be just as important as impacts of plants introduced by human agencies. There is a need for careful consideration of what type and degree of change in the vegetation is acceptable. This needs to come from a better understanding of the ecology of the Ashmore islands and other similar islands in the region. The most obvious example is to better understand the relationship between vegetation type and the requirements and preferences of different bird species for nesting habitat.

The islands are protected from the arrival of most non-indigenous plants by their distance from land and difficulty of access. The islands appear to offer a hostile physical environment for plant establishment and the human vectors are few.

Under present management regimes, the overall risk of further introduction of non-indigenous plant species to Ashmore islands and their establishment there are thought to be small. The major potential vector of species from Australia is thought to be through any landing of construction materials, land rehabilitation materials, and equipment (including scientific equipment) to the islands from Australia.

Indonesian fishing vessels are thought to provide the highest risk of introduction of major Asian weeds to the area. Probably of greatest significance for the Ashmore islands are *Boerhavia erecta* (Nyctaginaceae), *Chromolaena odorata* (Asteraceae) and *Cleome rutidosperma* (Capparaceae). In addition, the Asian native shrub, *Indigofera zollingeriana,* could potentially colonise the islands. It is a species of sandy beaches and coral strands.

Regular monitoring of plant species present on the islands is needed at an appropriate time of year (March-May). Annual monitoring would be ideal, but once every 3-5 years might be a more practical interval.

There is a need to maintain the current level of management presence at the islands to enforce present access restrictions for visitors and traditional fishermen.

Guidelines for personnel working on the islands need to be developed to address the potential problem of accidental introduction of seed of NIS with foot ware, materials and equipment, but could include the following:

- Minimise materials transported to islands (maintain minimal visitor facilities),
- Use new field equipment as far as possible,
- Wash down and/or de-seed any old equipment to go to the islands,
- Treat (sterilise?) any bulk materials to go to islands,
- Any plants for rehabilitation should be grown in soil-less mix in a weed free nursery area as per McDonald (unpublished),
- Research and management personnel should be encouraged to overnight on the boat unless there is a good reason to camp on land.

There is a need to better understand the differences in vegetation between islands, the underlying soil factors and the changes in vegetation taking place on the islands. There is also a need to build a knowledge base on non-indigenous plants invading similar coastal environments in monsoonal northern Australia and in Asia, especially islands used as sea bird nesting sites. Data on responses of individual NIS to the particular conditions associated with bird nesting sites are lacking.

A3.2 Introduction

The Ashmore islands (East, Middle and West) and Cartier Island are small islands located in eastern Indian Ocean, approximately 90 nautical miles south of Roti and 400 nautical miles west of Darwin (Pike and Leach 1997). The climate is wet-dry tropical with a highly seasonal rainfall of only 950 mm followed by a long dry season with evaporation of twice the annual rainfall (Commonwealth of Australia 2001). Soils of the islands are composed of carbonate sand, frequently underlain by a hard layer of cemented sand (calcrete). The three Ashmore islands are vegetated, while Cartier Island is a small, relatively steep sided sand cay, largely inundated at high tide and devoid of vegetation. All islands tend to be lower towards the centre, with higher the more mobile dunes forming a rim around the perimeter. The fore dunes of West Island and Cartier Island have been extensively used by nesting turtles, while East and Middle Islands support large populations of nesting sea birds (Fig. 1).

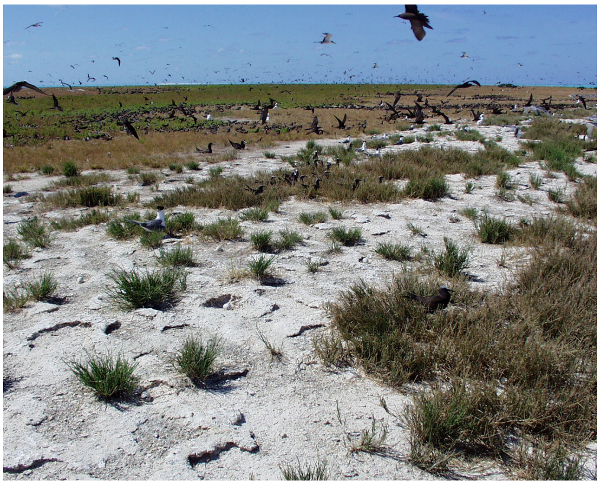

Figure 1: East and Middle Island support extensive populations of nesting sea birds. Guano accumulations can be seen in the foreground.

The plants of the Ashmore islands and Cartier Islet have been well documented (Pike and Leach 1997). The islands support a limited flora of terrestrial vascular plants consisting essentially of widespread tropical strand species adapted to a monsoonal climatic regime.

The flora of the Ashmore islands lacks endemic species but includes a number of species that have probably been introduced by humans. A dynamic element of the flora consists of the seedlings of tropical strand species germinating after dispersing to the islands, but failing to become established.

A3.3 Methods

Field Survey

A qualitative survey of non-indigenous plants and other terrestrial vascular plant species was undertaken on the Ashmore islands and Cartier Island between 10 - 21 June 2002. The island group was accessed by courtesy of the Australian Customs Service on the vessel "Holdfast Bay", sailing from Darwin, with each island accessed by dingy from the larger vessel and surveyed on foot. Particular attention was paid to searching the public access corridor and areas formerly utilised by humans (ie. the old ONA camp site, old Department of Territories caretaker's camp site, and old weather station installations, wells). Sites of former weed occurrence documented by Pike and Leach (1997) were also searched. Other parts of the islands were surveyed by searching along a series of randomly located transects. On islands with large colonies of breeding birds, disruption to the bird populations was kept to a minimum by using the beach as primary access with incursions into the interior. In order to avoid unduly alarming birds, a slow walking speed was adopted and sudden movements were kept to a minimum. The upper strand zone of all beaches on the islands was inspected visually and propagules (seeds, fruits and hypocotyls) and other flotsam collected. With this technique, there is probably a bias towards detection of the larger, more obvious propagules.

All terrestrial vascular plant species sighted were recorded, as it is possible for past assumptions about the native status of particular species to be overturned. Limited collections were made of plants of uncertain identity, to enable verification of field identifications and to supplement voucher material previously collected from the islands. As the survey coincided with the mid dry season, many annual plants were senescent and not readily identifiable. All specimens collected during this survey are accessioned, data based and stored at the Northern Territory Herbarium, Darwin and are available for future reference. Duplicate specimens were collected for forwarding to other Australian Herbaria, principally Australian National Herbarium, Canberra. All latitude and longitude data recorded during the survey were taken using a portable GPS unit using WGS 84 datum.

A3.4 Assessment of risks

The science of predicting which plant species will become invasive is not well developed. A range of habitat and biological features have been identified in the literature and may act either alone or together in predisposing a plant to becoming invasive. These predisposing factors include the taxonomic position, similarity of climate of area of origin to receiving area, ecological status, dispersal characteristics, seed dormancy, genetic systems and mode of reproduction (eg. Groves 1986, Williamson and Brown 1986). Thus, larger plant families generally contribute more weed species. Species from areas with climates similar to the receiving area may be better able to colonise. Plants, which are colonising species in their country of origin, may be more likely to be invasive in another area. Invaders frequently have propagules morphologically adapted to efficient dispersal. Plants, which are able to produce large numbers of seeds or plants having both sexual and asexual reproduction, are often invaders that are more successful. However, not all invasive species have these characteristics, nor are all species with these characteristics invasive (eg. the Orchidaceae is among the worlds largest plant families and orchids produce large numbers of seeds but are almost unknown as weeds). From a practical point of view, information on these predisposing factors is lacking in many instances.

It was considered that non-indigenous plants establishing on the islands (though not necessarily becoming invasive) are most likely to come from nearby areas with similar climates and soils. Northern Australia and much of eastern Indonesia have a wet-dry tropical climate with strongly seasonal rainfall (Russell and Coupe 1984). The Ashmore islands are also wet-dry tropical and have a rainfall of c. 950 mm per annum, with calcareous sandy soils (Commonwealth of Australia 2001). The rainfall of the Ashmore islands and many eastern Indonesian islands (< 1016 mm per annum) are close to that for Katherine and Timber Creek in the NT, but less than most inhabited parts of the NT north coast. Potential colonising species were identified using information available on coastal northern Australia, SE Asia and on other coralline islands of the NE Indian Ocean (Cocos Keeling Islands) and western Pacific. Unfortunately for the study, the Cocos Islands are 'wet tropical' with an annual rainfall of c. 1990 mm and are much closer in climate to Cairns than Darwin or Dili (Bureau of Meteorology 2001). The duration and intensity of the dry season was considered at least as important as total rainfall in influencing plant growth. In particular, plants already known as invasive weeds were included. Information was derived from the literature, from personal knowledge and from discussions with scientists familiar with the weed flora of the region. There is always the limited possibility that a weed native to tropical America could disperse to the islands without establishing in Asia first, although this possibility has not been considered further here.

A number of likely vectors were identified through the literature and in discussions with weed scientists, customs officers and others familiar with the region. Three types of invasion pathways were seen as of immediate concern to Australian authorities:

- Asia – Ashmore invasions,
- Australia – Ashmore invasions, and
- Ashmore – Australia invasions (including Asia – Ashmore – Australia invasions).

Potential modes of dispersal relevant to each species were identified from the literature, inferred from the structure of diaspores (dispersal units) and from previous experience of the species.

A3.5 Results and Discussion

Native Species

A total of 39 species of terrestrial vascular plant have been recorded from the Ashmore islands over a number of years, with 30 species recorded during this current survey (Table 1). During this current survey, 14 species were recorded from East Island, 15 species from Middle Island and 24 species from West Island. Details of plant collections from the islands held at the NT Herbarium are given in Table 2. No vegetation (apart from drift propagules and flotsam) was found on Cartier Island. The limited diversity of plant species recorded on the islands probably reflects the hostile nature of the environment, their small size and distance from external sources of seed. The parasitic vine *Cuscuta australis* was the only species not previously recorded from the islands (Fig. 2). It is native to central, south and east Asia and Australia (Queensland).

Despite intensive searching, a number of species were not relocated on any of the islands during the survey. These species included *Amorphophallus paeoniifolius, Boerhavia burbidgeana, Caesalpinia bonduc, Cassytha filiformis, Cenchrus echinatus, Eragrostis amabilis (*syn *E. tenella)* and *Melanthera biflora*. In addition, some species were not relocated on all islands where they had previously been recorded. A number of causes for these perceived changes are likely. Firstly the survey was undertaken during the dry season, and much of the vegetation had senesced and was not identifiable, affecting particularly slender annual species such as *Eragrostis amabalis*. Secondly, some species records were originally based on propagules, juvenile plants or individuals planted for food and these may have failed to become established (eg. *Caesalpinia bonduc, Zea mays, Rhizophora stylosa*). Thirdly, some weed species may have been eradicated (eg. *C. echinatus*) (Pike and Leach 1997). Fourth, there appear to have been natural extinctions of some species (eg. *Melanthera biflora*, *Spinifex littoreus* on East Island).

Figure 2: The parasitic vine *Cuscuta australis* (yellow stems) on *Tribulus cistoides* at East Island. *Cuscuta* was the only species not previously recorded from the islands.

Changes in the vegetation

While the present survey was not quantitative and mapping of the vegetation was not attempted, it is apparent that there have been sometimes significant changes in the vegetation since the surveys of Pike and Leach (1997). These authors also note the dynamic nature of populations of some grasses and small herbs. On East Island, the herb *Amaranthus interruptus* appears to have expanded increased considerably over that previously documented (Fig. 3), while on Middle Island there are large dead patches. It is possible that the species undergoes large fluctuations in abundance from year to year. A sizeable area of *Tribulus* also occurred, mostly in the centre of the island. On all islands, several herbaceous species noted by Pike and Leach were not relocated, although this could be due to season effects. On Middle and East Islands, many of the *Cordia subcordata* and *Suriana* bushes mapped have died (Fig. 4).

Figure 3: On East Island, the herb *Amaranthus interruptus* appears to have considerably expanded in distribution

Figure 4: Many bushes on East and Middle Island have died, possibly through guano build up and mechanical damage caused by nesting sea birds

Figure 5: *Spinifex longifolius* may be expanding its distribution on West Island, changing the vegetation from a low, sparse grass and herbland to a dense grassland

Spinifex longifolius may be expanding its distribution on West Island, changing the vegetation from a low, sparse grass - herbland c. 0.3 m tall to a dense grassland c. 0.7 m tall (Pike and Leach 1997) (Fig. 5).

Changes in the abundance of particular native plant species may be brought on by non-indigenous plants, or through various natural causes, including the birds themselves. One natural cause of the death of woody shrubs appears to be a byproduct of their heavy utilisation for nesting platforms (Fig. 6). The consequent mechanical damage, build up of guano deposits on and around the plants and quite possibly nutrient toxicity (both N and P) may be what kills the plants. The cause of recorded changes in abundance of annual and short-lived perennial species (eg. *Amaranthus*) is not immediately obvious, although similar changes in dominance of communities of annual species have been recorded elsewhere (Grubb *et al.* 1982). In floodplain plant communities of Kakadu, shifts in dominance were attributed to year to year variation in the pattern of early wet season storms and dry intervals through their effect on establishment of different plant species (Taylor and Dunlop 1985). Similar factors may also be important here.

Figure 6: Shrubs on Middle and East Island are heavily utilised for nesting platforms

Littoral Drift Species

Propagules (seeds, fruits and hypocotyls) of 44 species of terrestrial plants have been recorded as drift material on the beaches of the Ashmore islands (Table 3). Six species of species of drift seeds were recorded washed up on the beach at Cartier island (*Entada* sp., *Aleurites moluccana*, *Xylocarpus granatum*, *Guettarda speciosa*, *Terminalia catappa*, and *Corypha utan)*. The drift seeds *Canavalia* sp. and *Sophora tomentosa* had not previously been recorded at Ashmore. These are both widespread tropical legumes usually found growing in littoral habitats.

Twenty seven of the drift species are mangroves or wide spread strand plants with propagules adapted to dispersal by sea (van der Pijl 1982, Pike and Leach 1997). The seeds of these species readily survives immersion in salt water, in many cases remaining buoyant for in excess of 2 years and are likely to arrive at Ashmore in a viable state (van der Pijl 1982, Gunn and Dennis 1999). Certainly, seeds of *Barringtonia asiatica*, *Entada* spp. and *Nypa fruticans* washed up on NT beaches from overseas or perhaps Cape York germinated readily. At least 14 species are reported to have good viability when washed up on Christmas Island, Eastern Australia or elsewhere (Green 1999, Gunn and Dennis 1999, Smith 1999). For these species, it seems that a lack of viable propagules does not limit establishment on Ashmore islands. For mangrove species like *Cynometra ramiflora, Nypa fruticans, Rhizophora stylosa* and *Xylocarpus granatum*, there is a lack of suitable sheltered inter tidal habitat. A number of factors discussed previously may prevent establishment of others.

A number of species occurring in the littoral drift are more than likely washed into the sea by coastal streams (eg*. Aleurites moluccana*, *Barringtonia racemosa*, *Corypha utan, Pangium edule*). At least some of these are known to have lost their viability before reaching the islands (Pike and Leach 1997). Species like *Areca catechu*, *Mangifera indica* and *Annona squamosa* are probably part of the refuse from boats or coastal villages. It is unlikely that these species would arrive on the islands in a viable state, except perhaps where discarded from a nearby boat. This possibility is discussed further below.

Non-indigenous Species (NIS)

A total of 12 NIS have been recorded from the islands, with eight species recorded during the current survey (Table 4). At present, none of the few NIS found on the islands can be regarded as a major problem. No NIS dominate on the islands to the exclusion of all other native species, change the structure of the vegetation or interfere significantly with utilisation by wildlife. However, it is probably better to eliminate some species now (*Cenchrus ciliaris* and *Pennisetum pedicellatum* in particular) rather than take the risk that problems may develop in the future. They range from species established in a relatively small area on one island such as the grasses *Cenchrus ciliaris* (buffel grass) and *Pennisetum* *pedicellatum* to those which are more widespread and perhaps on several islands (*C. brownii*).

In many cases, the highest densities of non-indigenous plants were found in proximity to sites of former human occupation. The distributions of some species were restricted to these sites and may provide a clue to the era of their introduction. In particular, *Cenchrus ciliaris* and *Bulbostylis barbata* were found near the old Department of Territories camp on West Island. *Euphorbia hirta* and *Cenchrus brownii* were found near the old Meteorological installations and *Pennisetum pedicellatum*, *Cenchrus brownii* and a coconut palm were located near the old ONA foundation also on West Island. Coconut palms were located in close proximity to the Indonesian graves on West Island, and near the well on Middle Island.

The perennial grass *Cenchrus ciliaris* is an aggressive invader of coastal dunes around Darwin and of semi arid lands in central Australia, forming virtual monocultures in both situations. *Pennisetum pedicellatum* is a vigorous coloniser of disturbed situations in monsoonal parts of the NT. Both number less than 100 individuals each at the time of writing and could be eliminated from West Island with relatively little effort. Hand pulling or perhaps grubbing (if required) of plants on an annual basis for a number of years would be all that is needed. For the annual plant *P. pedicellatum* this should be done towards the end of the wet season before seed has set, but late enough in the season so that the grass can be recognised (say late March to April). The perennial *Cenchrus ciliaris* could be removed at any time of year, but may be difficult to recognise outside its flowering period. Any seed heads should be removed first to minimise spread of seed, and the vegetative parts pulled up and left to dry off.

Tribulus cistoides is a prostrate perennial herb producing sharp-pointed burrs, which become embedded in foot ware. The species is probably native to Africa but is now a pantropical weed inhabiting sandy beaches and dunes (El Hadidi 1985, Dassanayake 1988). It was present in north-eastern Australia in 1770 and is presumably a pre-European introduction there (Barker 1998). *Tribulus* is well established on all three Ashmore islands. Extensive patches occurred towards the south end of East Island, with occasional plants on the east side of Middle Island. Sea birds on East Island appeared to avoid dense patches of *Tribulus* for nesting. One patch of c 3m x 4 m was found towards the north end of West Island (Table 1). The populations on West and Middle could be removed with some effort but those on East Island would be more difficult and removal operations would be disruptive to sea bird nesting. On East Island, the edges of *Tribulus* patches were parasitised by the slender vine *Cuscuta australis*, which may serve to provide some measure of control.

The annual burr-producing grass *Cenchrus brownii* is present in sizeable populations on West Island but was not relocated on Middle and East Islands, perhaps due to seasonal effects or local extinction. Elimination would be more difficult than for *C. ciliaris* and *P. pedicellatum* and would need a reasonable effort over a number of years, but could still be achieved through hand pulling.

Cenchrus echinatus is an annual, burr-producing grass and was not relocated during the survey. Pike and Leach (1997) indicate that eradication measures have been taken against the species and the only recorded infestation on West Island may well have been eliminated.

Cleome gynandra is an annual herb to c. 60 cm tall. It is a widespread tropical weed and is probably introduced on Middle Island. It appears to have significantly extended its range over that documented by Pike and Leach, a trend also noted by those authors. It is now scattered over an area extending from the old well and coconuts to c. 200 m to the E of there. The value of removal of the species may be debatable as the plants frequently occur in sparsely vegetated areas where few other species were currently growing, with some birds nesting under the low canopy. Again, control or elimination could probably be achieved by hand pulling, repeated towards the end of each wet season over a number of years.

Euphorbia hirta is a short perennial or annual herb usually less than 20 cm tall at Ashmore and is a widespread weed in the tropics. On the Ashmore islands, it is restricted to vicinity of the old weather station on West Island. It is hardy and able to colonise coastal habitats away from obvious disturbance but does not appear to form monocultures either on West Island or on coastal dunes in NT.

Bulbostylis barbata is a small annual herb growing to c 15 cm tall, probably of little consequence at Ashmore. It is widespread in warm parts of the world and is native to Australia, occurring as far south as northern NSW. On West Island it was found only near the old Department of Territories camp, suggesting it may be introduced. In the NT, it is a frequent minor component of vegetation on shallow soils and sands, including coastal dunes.

A3.6 Assessment of risks

The potential impacts of plant species native to the region and dispersing naturally to the islands may be just as important as impacts of non-indigenous plants. The islands have a small flora and are isolated by a considerable distance of sea from other areas, with limited opportunities for dispersal there. As such many species native to the region may be yet to reach the islands, but once there could spread altering the structure of vegetation and the abundance of other species in the process. *Spinifex longifolius* may be a natural example of this process currently taking place on West Island. Conversely, over utilisation of shrubs for nesting sites appears to be resulting in their death, especially on Middle Island. If this process continues, shrubs could be eliminated from some islands, with possible effects on the quality of nesting habitat for some bird species. There is a need for careful consideration of what type and degree of change in the vegetation is acceptable, and this probably needs to come from a better understanding of the ecology of these and other similar islands. The most obvious example is to better understand the relationship between vegetation type and the needs and preferences of different bird species for nesting habitat.

The islands are likely to offer a hostile environment for plant establishment and growth, limiting both the human-introduced plants as well as the many species of plant arriving naturally on the island. The climate is wet-dry tropical with a relatively low, highly seasonal rainfall followed by a long dry season with high evaporation and temperatures especially late in the dry season (Commonwealth of Australia 2001). Although detailed scientific data are lacking, soil on the islands is essentially sand, and is probably unfavourable to plant growth in many ways. It is mostly excessively well drained, probably with a low nutrient holding capacity and high pH, in places cemented and with a shallow effective soil depth, or saline from periodic inundation by the sea (eg. Cartier Island). On the islands with substantial populations of nesting seabirds, soil nutrient concentrations may be at or near toxic levels in places. Mechanical disturbance of fore dunes by nesting turtles probably also contributes to the difficult conditions.

There may be substantial differences between the islands in the conditions for plant establishment and growth, and these conditions could have a strong influence on the species of non-indigenous plant establishing and flourishing there. The possibility cannot be over looked that at least some of the differences in the vegetation between the islands are due to the different vertebrate fauna using them. Middle and East Island have large numbers of birds nesting on them, while West Island has few nesting sea birds (a few tropic birds), but the fore dunes are heavily utilised by turtles. Sea birds, through the deposition of nutrient-rich guano and turtles through the extensive excavation of dunes probably affect conditions for plant establishment and growth in different ways. West Island has a well developed fringe of *Argusia* shrubs, and the herbaceous vegetation has a high proportion of *Sida pusilla, Digitaria mariannensis* and *Boerhavia repens*, with extensive patches of *Ipomoea macrantha*, *I. pes-caprae* and *Spinifex longifolius*. The vegetation of this island is similar to coastal dune vegetation in parts of the Northern Territory. Some species common on West Island (eg. *Sida pusilla, Boerhavia repens, Ipomoea macrantha*) formed a low proportion of the vegetation or were missing from Middle and East Islands, where *Amaranthus interruptus* and *Eragrostis cumingii* were highly abundant. Some species such as the annual grass *Digitaria mariannensis* and the perennial dune grass *Lepturus repens* were common on all islands.