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Research Article

Marine pests in paradise: capacity building, awareness raising and preliminary introduced species port survey results in the Republic of Palau

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Abstract

Introduced marine species can have a large impact upon small countries that are reliant on marine tourism. Non-governmental organisations, such as the World Conservation Union (IUCN), are working with technical experts to implement capacity building and awareness programs that transfers introduced marine species knowledge to countries in need of aid. The Republic of Palau is reliant on tourism and as such is pro-actively engaging in this process to ensure that it has the necessary skills to determine and manage its introduced marine species pathways and vectors. The IUCN with the aid of technical experts implemented a four day training workshop that provided both theoretical and practical field experience with introduced marine species port surveys. An outcome of this exercise was the detection of 11 introduced marine species, the training of 10 Palau agencies and two international organisations, and recommendations for future implementation that will aid Palau to address the problem of introduced marine species within their borders.

Key words: non-indigenous species, non-native species, marine pests, biofouling, biosecurity, environmental management, species criteria, Pacific Island Countries

Introduction

Within the last two decades research on introduced species has expanded from a focus on ballast water mediated transport (e.g., Williams et al. 1988; Carlton and Geller 1993), to a more holistic view of potential vectors (e.g., Carlton 2001; Hewitt et al. 2004; Padilla and Williams 2004; Fofonoff et al. 2003; Campbell and Hewitt et al. 2013; Williams et al. 2015). Marine invaders have now been detected in virtually all regions of the world oceans, with indications that multiple vectors contribute to these broad-scale distributions (e.g., Hayes et al. 2005; Hewitt and Campbell 2007). Not all countries have the capacity to determine the current state of invasions within their waters or the ability to implement pro-active biosecurity measures (e.g., Bax et al. 2003; Hewitt and Campbell 2007; Nuñez and Pauchard 2010; Azmi et al. 2015a, 2015b). This lack of capacity has serious biosecurity implications. Of particular concern is the reliance of a number of small island states, specifically Pacific Island Countries (PICs), on their marine environments, to the extent that the "marine economy" derived from tourism, artisanal and commercial fisheries and aquaculture contributes more than 10% of Gross National Income (GNI) in many instances (Table 1).

The marine economy is a useful term to capture the direct and indirect benefits derived from marine based activities to GNI, which need to be examined in the context of marine biosecurity. Marine economy activities include more traditional economic drivers, such as commercial export based fisheries, aquaculture, aquarium species collection, and oil and gas extraction; as well as subsistence fisheries and marine based tourism (see Table 1). While traditional economic drivers have previously been calculated for contribution to GNI, it is commonly realised that the ability to capture less traditional aspects in PICs is limited, resulting in an under-estimation of GNI

Table 1. Pacific Island countries Gross Domestic Product (GDP), currency, and the percentage "marine economy" component of the GDP, with the Republic of Palau highlighted by italics (source: Gillett and Lightfoot 2001). * – estimate

Country	GDP	Currency	Marine component (%)
Cook Island	$171,599,000	NZ$	11.31
Federated States of Micronesia	$229,869,864	US$	4.70
Fiji Islands	$3,587,300,000	F$	2.34
Kiribati	$74,100,000	AUD$	11.98
Marshal Islands	$97,311,800	US$	7.40
Nauru*	$80,000,000	AUD$	2.12
Niue	$14,210,300	NZ$	1.58
Palau	*$129,601,000*	*US$*	*2.69*
Papua New Guinea	$8,780,800,000	Kina	0.56
Samoa	$705,914,000	Tala	7.99
Solomon Islands*	$1,352,700,000	SI$	0.01
Tonga	$251,135,000	T$	7.13
Tuvalu	$22,044,500	AUD$	6.77
Vanuatu	$29,206	Vt million	0.95

contribution (e.g., Gillett and Lightfoot 2001; Gibson and Nero 2008). For many PICs, fisheries can account for more than 10% contribution to GNI, with marine based tourism having an equal or greater share.

Despite a high reliance on the marine environment and marine resources for economic well-being, many of these PICs have limited understanding about introduced marine species and the risks they pose to their economies. As Nuñez and Pauchard (2010) have discussed, these developing states have limited capacity or capability to meet the demands of marine biosecurity within their domain. To address this, a number of non-governmental and intergovernmental organisations have established programs to ensure that all countries have access to information about marine introduced species (awareness raising) and can receive expert training (capacity building) to facilitate regional and international outcomes.

Two examples of this proactive international stance include: 1) the work undertaken by the Global Ballast Water Management Programme (referred to as GloBallast) — a collaboration between the Global Environment Facility (GEF), United Nations Development Program (UNDP) and the International Maritime Organisations (IMO) (IMO 2000a); and 2) the IUCN's marine programme (IUCN 2013), with a third organisation unfortunately closing in 2011 (the Global Invasive Species Programme [GISP]; BGCI 2011). These organisations have provided training for introduced species surveys, identification and taxonomy, risk assessment, ballast water management, and public awareness in a number of countries.

Phase I of the Globallast programme undertook introduced species port survey training in six countries (Brazil, China, India, Iran, South Africa, and the Ukraine). This training provided basic skills in ballast water management, ballast water risk assessment, and taxonomic identification (IMO 2000b). In general, these initiatives targeted stakeholders such as universities, museums, navy, and port authorities. GISP had maintained a broader, all-ecosystem approach to invasive species providing for example, public awareness (e.g., invasive species posters), training workshops, and advice to decision makers (e.g., Simons and de Poorter 2008). Similarly, the IUCN provides introduced species awareness raising in countries such as Chile (e.g., Hewitt et al. 2006), the Seychelles, and Samoa, and have also undertaken some targeted introduced species surveys (e.g., Tamelander et al. 2009).

One example of the IUCN efforts is a facilitation and capacity building exercise conducted in the Republic of Palau (herein referred to as Palau) in 2007 on introduced species port survey methods, both theoretical and applied. This paper provides an overview of the exercise, including outcomes derived from the workshop. The work in Palau involved a number of different in-country agencies, working with Australian marine biosecurity experts who provided training that was facilitated by the IUCN and the Office of Environmental Response and Coordination, Palau. The activity in Palau focussed on providing an awareness of introduced marine species and the problems they cause, training interested agencies in port survey techniques and taxonomic sorting, and introducing the concepts of risk assessment.

One of the main objectives of this work was to ensure that Palau would receive training in skills that would allow them to undertake their own introduced species baseline surveys and establish monitoring programs, thus ensuring that knowledge transfer occurred. It is anticipated that follow-up surveys within Palau will further build capacity and increase knowledge about introduced marine species in this region. Outcomes from the training exercise provided preliminary data on the introduced species present in the region and associated vectors that may pose a risk to Palau. This type of information can then form the basis of informed introduced species management programs.

Materials and methods

Training workshop

Between 25th and 28th July, 2007, 10 Palauan agencies (Bureau of Marine Resources, Bureau of Agriculture, CARP Dive Tour Company, Koror State Government, Office of Environmental Response and Coordination (OERC), Palau Conservation Society, Palau International Coral Reef Centre, Coral Reef Research Foundation, Peleliu State Government, Sam's Tours) and two international organisations (IUCN, The Nature Conservancy) were trained in introduced marine species baseline survey design and techniques, including undertaking a preliminary survey of Malakal Harbour, Koror State, Palau, sample sorting and para-taxonomic species identification. It is important to note that the para-taxonomic training was focussed on identifying obvious non-native species (building capability) and providing knowledge about where to find taxonomic information, such as relevant databases or how to contact taxonomic experts. The supplementary material in this paper provides a list of taxonomic databases and references that we typically provide during port survey capacity building training.

A component of the project included in-water training of methods and post-survey taxonomic sorting with species identification. The survey training specifically covered the Hewitt and Martin (1996, 2001) protocols, with further information provided during a workshop on alternative protocols such as the Rapid Assessment Survey (RAS) surveys (e.g., Cohen et al. 2001, 2005; Pedersen et al. 2003), the Bishop Museum protocols (e.g., Coles and Eldredge 2002), the Chilean aquaculture survey protocols (e.g., Hewitt et al. 2006), and passive sampling (Ruiz and Hewitt 2002; Wyatt et al. 2005; deRivera et al. 2005).

Workshop participants designed a baseline survey, grounded by their shared local knowledge coupled with their training in the Hewitt and Martin protocols (1996, 2001). As with all baseline port surveys; the aim of the developed survey was to detect introduced marine species through examination of marine biodiversity. Therefore, survey sites were selected based on likely primary inoculation points (areas with overseas linkages) and secondary sites with high frequency of visitation from primary inoculation points (i.e., secondary transfer locations). In addition, sites of high environmental, economic or socio-cultural importance were identified for monitoring.

Upon return from the field a literature search was undertaken to identify known introduced and cryptogenic species from the region to inform the development of a biosecurity framework specific to Palau.

Survey site

Palau is an archipelago of over 586 islands (eight main islands) located east of the Philippine island of Mindanao; the first Europeans to see the islands were the Spanish in the 1500's (Faulkner et al. 2004; Yukihira et al. 2007). It is a biodiversity hotspot (Faulkner et al. 2004; Yukihira et al. 2007) and a well-known international tourist destination based on its Rock Islands, jellyfish lakes and unique SCUBA diving opportunities (Yamashita 2000). The government is proactive, with regards to introduced pests and are concerned with the potential impact introduced marine species pose to their tourism (including charter fishing) industries.

Introduced species survey methods

The preliminary survey served two purposes: 1) to train the survey team in introduced species survey methods; and 2) to undertake a preliminary examination of the species present in Malakal Harbour. The survey aimed to detect introduced marine species and provide an indication of their spatial distribution. Collection of native biodiversity data was a secondary aim of the survey plan. Within this paper we discuss the detection of introduced marine species, not native species.

An initial suite of survey sites were selected by introduced species port survey specialists for consideration by the workshop participants. This selection of sites was subsequently discussed with workshop participants to add local knowledge and thereby improve site selection by adding or removing sites where needed. This ensured that selection of sites was refined and prioritised based on the heuristic knowledge of the workshop participants, coupled with the prioritisation knowledge provided in the Hewitt and Martin (2001) introduced species sampling principles (Table 2). At the end of the heuristic workshop process, a total of 38 sites were identified,

Table 2. Sites selected for introduced marine species surveys, including method of sampling, heuristic priorities and introduced species priorities. Italic font indicates sites that would be sampled under a typical introduced marine species survey using the Hewitt and Martin (1996, 2001) protocols.

Site name	Method	Heuristic priority	Introduced spp priority
Training sites covered			
Neco floating dock	*Qualitative*	*2*	*1*
Neco marine dock	Quantitative	2	1
PMIC	*Quantitative*	*1*	*1*
Sam's Tours	*Quantitative*	*1*	*1*
Channel marker	*Semi-quantitative*	*2*	*1*
Bureau of Marine Resources/Belau -Mariculture Demonstration Center	*Quantitative*	*1*	*1*
Marine Law Enforcement	*Quantitative*	*1*	*1*
Commercial Berth 3 (south)	*Quantitative*	*1*	*1*
Commercial Berth end	Qualitative	1	1
Phase 1 – Malakal port sites			
Malakal causeway	*Quantitative*	*3*	*2*
Palau Royal Resort	*Quantitative*	*2*	*1*
Carp Restaurant	Quantitative	2	1
Fisheries wharf	Quantitative	2	1
Palau Island Traders International	Quantitative	1	1
BRM - mariculture	*Quantitative*	*1*	*2*
Marine law	*Quantitative*	*1*	*1*
Barge wreck	Qualitative	2	3
CPR – dry dock	*Quantitative*	*2*	*1*
Chandelier cave	Qualitative	3	4
Recreational anchorage	*Qualitative*	*1*	*1*
Recreational anchorage – Chinese wreck	Qualitative	1	3
Recreational anchorage - wreck	Qualitative	1	3
Old Japanese dry dock	*Qualitative*	*3*	*1*
Phase 2 – external to port – Koror State			
Channel buoys 1	*Semi- quantitative*	*1*	*1*
Channel buoys 2	*Semi- quantitative*	*1*	*1*
Channel buoys 3	*Semi- quantitative*	*1*	*1*
Derelict tugs	*Qualitative*	*1*	*3*
Large foreign vessel anchorage Pincher Bay	Qualitative	3	3
PPR	*Qualitative*	*3*	*2*
Sea plane anchorage	Qualitative	3	1
T-dock (historical jetty)	*Qualitative*	*2*	*1*
KB (JP) bridge - north	Quantitative	1	2
KB (JP) bridge - south	Qualitative	1	2
Fish & fins/PICRC	*Quantitative*	*2*	*1*
Dump site	Qualitative	3	2
Ngetkedam	Qualitative	3	3
Anchorage – near helmut dive site	Qualitative	3	1
MV "Pristine"	*Qualitative*	*2*	*3*
Phase 3 – beyond Koror State (To be designed)			

within a three phase program (phase 1 – Malakal Harbor; phase 2 – surrounding regions within Koror State; and phase 3 – areas outside of Koror State) being suggested to complete the site survey. This paper concentrates on phase 1, with phases 2 and 3 underway via the Koror Rangers at times of their convenience.

Typically, an introduced species survey for a region of this size would sample fewer sites (e.g., 22 sites) but retaining the ability to detect low density invasions (e.g., Hewitt and Martin 2001). Indicated in Table 2 (via italic font) are the sites that would be sampled during a full Hewitt and Martin style survey. By sampling fewer sites but maintaining a high detection limit (statistical ability to find an introduced species based on the sampling effort expended), the efficiency of the survey is increased both with regards to resource use and statistical robustness. However, when training participants, it is often desirable to include more sites to ensure the inclusion of stakeholder opinion.

A number of sites that were sampled through visual inspection (qualitative sampling) were added

Figure 1. A selection of the survey sites in Palau: Malakal Harbour (A, B), “pristine” areas (C, D), and tourist sites (E, F).

to the survey in an ad-hoc fashion, with introduced or suspect introduced species being noted at all ad hoc sites. Samples from the hulls of three vessels were also collected in a qualitative fashion. Fouling communities were sampled at 16 sites; nine sites within Malakal Harbour and seven sites outside of the harbour, including three “pristine” sites in the Rock Islands (Figure 1). Standard 0.10 m^2 quadrats were used to sample hard substrate using the methods described in Hewitt and Martin (1996, 2001). Quadrats were sampled at three depths (–0.5m, –3m, and –7m) in triplicate (n = 9 samples) where depth allowed. When depths were limited (too shallow), two depths (–0.5m and –3m) were sampled using four replicates (n = 8 samples). During this preliminary survey no benthic cores, phytoplankton or pelagic samples were collected and hence sampling focussed on biofouling communities.

Collected specimens were placed on ice until taxonomic sorting and identification occurred on the afternoon of the day that collection occurred. Specimens were preserved using 70% ethanol and labels were used to ensure that site and specimen integrity was maintained following the methods of Hewitt and Martin (1996). Specimens were identified to least taxonomic unit, aiming to obtain a species level identification, so that species status (is it a native, introduced, cryptogenic species) could be derived. A number of para-taxonomic experts were involved in the species identifications.

Identifying a species status

A modified version of the Chapman and Carlton (1991, 1994) 10-point criteria was used to determine a species status (Table 3; Campbell et al., *in review*). These criteria evaluate ecological, geographical and evolutionary attributes of a species, using deductive reasoning to aid in the determination of a species status. Knowledge that spans across multiple disciplines, such as taxonomy, phylogeny, genetics, ecology, biology, and biogeography, is used to assess the species status. The modified criteria have been trialled (e.g., Brazil, China, India, Iran, Samoa, the Seychelles) in regions where a historical track record of native species exist and worked relatively well (M Campbell, unpublished data).

The modified criteria include an additional five criteria to those that Chapman and Carlton (1991, 1994) originally suggested. These new additions were derived by evaluating native and introduced species patterns from national and international port survey data sets (Australia, South Africa, Brazil; Pollard and Hutchings 1990a, 1990b; Hewitt et al. 1999, 2004; Hewitt and Campbell 2001; Hewitt 2002; Campbell 2003; Campbell et al. 2004; Hewitt and Campbell, unpubl. data) and readily available international species data present in the published literature (e.g., Cohen and Carlton 1995; Ribera and Boudouresque 1995; Brattegard and Holthe 1997; Zaitsev and Mamaev 1997; Cranfield et al. 1998; Zaitsev and Alexandrov 1998; Coles et al. 1999; Boudouresque and Verlaque 2002; CIESM 2002; Galil et al. 2002; Leppäkoski et al. 2002; Orensanz et al., 2002; Green and Short 2003; Occhipinti-Ambrogi and Savini 2003; Castilla et al. 2005). To determine if a species was native, introduced or cryptogenic, a "weight of evidence" approach was applied. Three of the new criteria are based on patterns linked to an introduced species affinity with mediated transport mechanisms (such as vessels and aquaculture) that lead to a broader distribution than may be observed by naturally dispersing natives and are summarised as:

- Criterion 7: The local (<10's km) distribution of the introduced species is wide when compared to similar native species' local distributions;
- Criterion 8: The regional (100's – 1000's km) distribution of the introduced species is wide when compared to similar native species' regional distribution;
- Criterion 10: Introduced species have a widespread global distribution;
- Criterion 14: Only one sex of a dimorphic species can be detected. Several introduced species have been identified where a single sex is detected and reproduction is limited to asexual means alone. Founder effects may result in a reduced probability of individuals of both sexes being introduced to a locale; and
- Criterion 15: This genus is not present in the country/island/continent (higher taxonomic affinities are lacking).

Results and discussion

Training workshops

A four day workshop was conducted that involved 10 Palauan and two international organisations. The initial 2 days involved classroom activities, where participants were trained using a more traditional style "chalk and talk" information provision session followed by information transfer with group activities. During the "chalk and talk" session experts discussed what introduced marine species are, the different field survey techniques that exist for detecting introduced species (*sensu* Campbell et al. 2007), and how risk analysis can be used for marine biosecurity (e.g., Campbell 2008; Campbell and Hewitt 2011, 2013).

Within the group activities a "strawman" model of a Hewitt and Martin port survey for Malakal and surrounding regions was provided to participants. The workshop participants then used their newly acquired introduced species and survey knowledge, plus their local knowledge to modify sites and decide the best sampling techniques for each subsequently selected site (Campbell and Hewitt 2008). This combined method resulted in participants stating that they felt confident that they had the skills to understand, plan and implement a baseline survey for introduced species with minimal guidance from experts.

The remaining two-days of the workshop involved field activities where a group of people that would be involved in undertaking port surveys had in-water training in the field sampling and laboratory sorting techniques. This training resulted in nine sites being surveyed with additional ad hoc collections. The preliminary survey detected introduced species and as such is considered to be a successful implementation of a knowledge and skills capacity building exercise.

Table 3. Criteria used to determine if a marine species is introduced, cryptogenic or native (from Campbell et al., *in review*). The criteria are modified from Chapman and Carlton (1991), with the exceptions of new additions, which are highlighted in **bold** font and shaded background.

Geography	Criterion	Description
Provincial	1	Sudden local appearance
Provincial	2	Subsequent local spread
Provincial	3	Distribution associated with human mechanisms of dispersal
Provincial	4	Trophic dependence (and symbioses) on known introduced marine species
Provincial	5	Most prevalent in, or restricted to, new or artificial environments
Provincial	6	Local distribution restricted compared to native species
Provincial	**7**	**Local distribution wider when compared to native species**
Provincial	**8**	**Regional species distribution wider when compared to native species**
Global	9	Disjunct global distribution
Global	**10**	**Widespread global distribution**
Global	11	Active dispersal mechanisms are inadequate to attain current global distribution without human aid
Global	12	Passive dispersal mechanisms are inadequate to attain current global distribution without human aid
Global	13	The species is most similar morphologically, or genetically, to species in other regions of the world
Global	**14**	**Only one sex of a dimorphic species can be detected**
Global	**15**	**This genus is not present in the country/island/continent (higher taxonomic affinities are lacking)**

Baseline survey results

The preliminary field survey detected 11 introduced and two cryptogenic and seven potentially introduced species (Table 4). The introduced species were dominated by bryozoans (46%), followed by ascidians (27%), hydroids (18%) and barnacles (9%). Taxa from the ascidians, polychaetes and porifera are potentially introduced and need further analysis to confirm their identity. These species were detected in association with wharf facings, floating docks, channel markers, and as biofouling on international vessel hulls. Fourteen percent of the species detected on international vessel hulls were not detected in the port environs, inferring that international vessels are a potential vector of concern as they may transfer new species to the region.

Historically, and in modern times, biofouling is one of the primary mechanisms that introduced marine species are transferred between locations (Godwin 2003; Hewitt et al. 2004; Ashton et al. 2006; Davidson et al. 2008; Hopkins and Forrest 2008; Mineur et al. 2008; Lee and Chown 2009; Galil et al. 2014). This vector is relatively poorly managed (Hewitt and Campbell 2007; Lee and Chown 2009), although a number of countries have introduced guidelines regarding vessel management that specifically targets introduced marine species vectoring via biofouling (e.g., USA: California Hull Fouling Legislation Assembly Bill 740 (AB 740)). It's not surprising that a lag period for development and implementation of biofouling management guidelines exists, given the 14-year lag period we've seen for the adoption of the International Convention for the Control and Management of Ships Ballast Water and Sediments Ballast Water Convention in 2004.

A number of species of concern, that can become pests, or are known as pests elsewhere, were detected (e.g., the hydroids *Eudendrium carneum* Clarke, 1882 and *Thyroscyphus fruticosus* (Esper, 1793), the bryozoan *Watersipora subtorquata* (d'Orbigny, 1852), and a tentative identification of the Caribbean barnacle *Chthamalus proteus* Dando and Southward, 1980). These species have the potential to impact on native fauna and flora in Palau, due to their propensity to heavily foul substrata. Both *E. carneum* and *T. fructicosus* were previously known and are believed to have been introduced with a floating bridge that came from China in 1996 (Lambert 2002; Colin 2009). The method of introduction for the other species is unknown but likely associated with vessel biofouling given that Palau receives little international ballast water but it does receive a large number of recreational vessels (such as touring yachts).

Of concern is that some of the species detected have the potential to become pest species and damage tourist destinations. A similar situation has already occurred in Palau, with the introduction of the cnidarian, *Aiptasia* sp., into one of the major international tourist destinations, Ongeim'l Tketau (Jelly Fish Lake; Colin 2009), located on the rock island of Mecherchar. Palau relies on the tourism industry, with 11% of the gross domestic product being tourist related (US Department of State 2012) and thus impacts upon drawcard tourist destinations could have serious implications for the country's economy.

Table 4. Detected introduced, cryptogenic and potentially introduced species during the preliminary Palau introduced species survey. Species are listed with an indication of the sampling locations/sites (wharves, moorings, vessel hulls, or "pristine" locations without commercial activity). A "●" indicates presence upon a substrate. Please note that scientific names and taxonomic authorities (for species names) were verified using the WoRMS database (http://www.marinespecies.org/).

Phyla	Species	Status	Wharves	Vessels	Mooring	Pristine
Porifera	*Haliclona caerulea?* (Hechtel, 1965)	Potential	●		●	●
	Mycale sp. (orange sponge)	Potential	●			●
Hydroida	*Eudendrium carneum* Clarke, 1882	Introduced	●			
	Obelia sp.	Cryptogenic	●	●	●	
	Thyroscyphus fruticosus (Esper, 1793)	Introduced	●		●	
Polychaeta	*Sabellastarte* sp.	Potential	●			
	Serpulididae	Potential	●	●		
Cirripedia	*Amphibalanus amphitrite* (Darwin, 1854)	Cryptogenic (cosmopolitan)	●	●		
	Chthamalus proteus Dando and Southward, 1980	Introduced			●	●
Bryozoa	*Amathia distans* Busk, 1886	Introduced	●	●		
	Viridentula dentata (Lamouroux, 1816)	Introduced	●			
	Bugula neritina (Linnaeus, 1758)	Introduced	●	●		
	Tricellaria occidentalis (Trask, 1857) / *T. inopinata* D'Hondt and Occhipinti Ambrogi, 1985	Introduced	●		●	
	Watersipora subtorquata (D'Orbigny, 1852)	Introduced		●		
Ascidia	*Ascidia sydneiensis* Stimpson, 1855	Potential	●			
	Botryllus sp. (*cf. niger*)	Potential	●		●	
	Didemnum perlucidum Monniot F., 1983	Introduced	●	●		
	Phallusia nigra Savigny, 1816	Introduced	●			
	Diplosoma listerianum (Milne Edwards, 1841)	Introduced	●			
Pisces	Gobiidae sp.	Potential	●			●

Styela plicata (Lesueur, 1823), a species that is native to Palau, but has been introduced to Australia (e.g., Glasby 1999; Wyatt et al. 2005) and elsewhere (e.g., da Rocha and Kremer 2005; de Barros et al. 2009), was detected in moderate densities at the commercial wharves on facings. This species is a pest in some regions (e.g., Glasby 1999), reaching high densities and fouling infrastructure (e.g., Glasby 1999; Connell 2000). Given the presence of this species in the port environment, it is possible that Palau may act as a donor region for this species, with a pathway related to international recreational vessels that visit Palau during larger treks.

Pre-existing literature

Previous introduced species and biodiversity research from Palau (Lambert 2002; Golbuu et al. 2005; Colin 2009), and the wider Indo-Pacific biogeographic region including: tropical Australia (Hewitt 2002), Guam (Paulay et al. 2002), Samoa and American Samoa (P. Skelton, pers. comm.), had collectively identified 127 introduced or cryptogenic marine or estuarine taxa. Ascidians represent a substantial portion (33%) of these introductions, followed by bryozoans (11%), hydroids (11%) and then bivalves (9%; Figure 2). Based on life-history characters and the timing of likely introduction, species were assigned association with primary vectors of introductions (e.g., ballast water, vessel biofouling, intentional aquaculture species and hitch-hiker aquaculture species). The majority of species (98%) have traits that indicate vessel biofouling is the highest likelihood vector, however the vectors of ballast water (40%), aquaculture hitch-hikers (39%) and intentional introductions (31%) have a substantial proportion of species that may have been transported by these means.

Within Palau, six introduced and 13 cryptogenic species have been identified through biodiversity work undertaken by the Coral Reef Research Foundation (Lambert 2002; Colin 2009; supplementary material Table S1). Within (Western) Samoa and American Samoa, nine introduced species have been detected (P. Skelton, pers. comm.; Table S1). Similarly, within Guam 40 introduced and 45 cryptogenic species have been detected by surveys using the Bishop Museum protocols (Paulay et al. 2002; Table S1). Surveys using the Hewitt and Martin protocols have detected 25 introduced species and six cryptogenic species within tropical Australia (Hewitt 2002; Table S1).

Of the potential and possible introduced species in Palau, there are no shared introduced and cryptogenic species with tropical Australia; however Palau

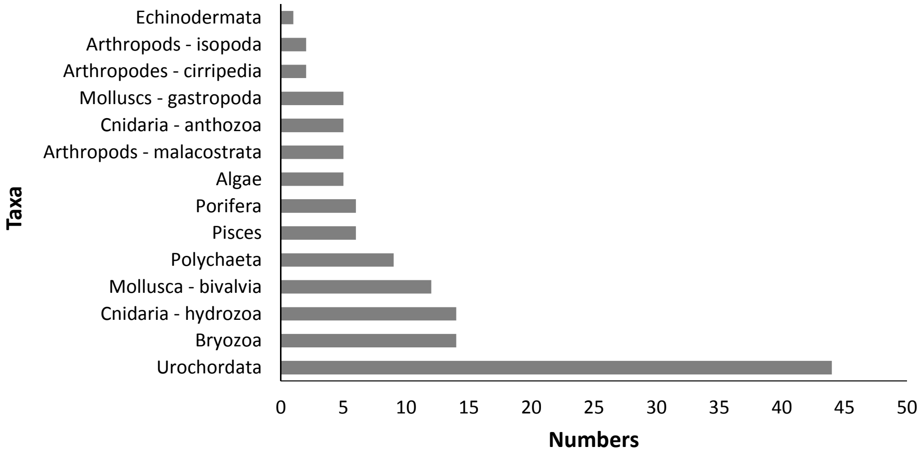

Figure 2. Number of introduced and cryptogenic marine species by taxa introduced into Palau, Guam, Samoa and tropical Australia.

and Samoa share one introduced species (*T. fruticosa*), and Palau and Guam, share three introduced species (*Didemnum perlucidum* Monniot F., 1983, *Diplosoma listerianum* (Milne Edwards, 1841), *Lissoclinum fragile* (Van Name, 1902)). The lack of species-sharing between regions may be an artefact of taxonomic effort, or a result of the qualitative versus quantitative nature of the survey sampling methods used in these areas. Alternatively, this lack of overlap may also be due to the dearth of pathways shared between the regions; however this seems unlikely given that these regions are historically linked by wartime activity during WWII, and currently linked by recreational traffic (Oliver 1989; Marti 2004) and in some instances commercial traffic (Campbell and Hewitt 1999; Ruiz et al. 2015). We note however, that commercial traffic has been reduced with modernisation of ports and vessels (e.g., Ward 1989).

Detecting and identifying introduced marine species

The combined literature review and preliminary baseline survey identified a total of 11 introduced, 17 cryptogenic and 12 potentially introduced species for Palau. These species were typically associated with artificial substrates, such as wharves, floating buoys and vessel hulls.

Recommendations

When this research was undertaken Palau had two pieces of legislation relating to non-native species: Palau National Code Title 25, Chapter 20 refers to Quarantine laws; and in 2004 Palau published the Palau National Invasive Species Strategy (https://www.cbd.int/doc/submissions/ias/ias-pw-strategy-2007-en.pdf), which included the establishment of The National Invasive Species Committee (NISC). In 2006, the position of National Invasive Species Coordinator was created and filled; this position also acts as the secretary for the NISC. In March 2016, the Palau President signed into law the Biosecurity Act (http://www.paclii.org/pw/legis/num_act/ba2014rn9582015241/). This new law contains an update to Quarantine laws (http://www.islandtimes.us/index.php?option=com_content&view=article&id=644:biosecurity-bill-becomes-law). Many aspects of the early legislation is focussed or implemented in an agricultural and land management context, with an outward focus on preventing pest species reaching Palau. After this initial training exercise (as described in this paper), non-native marine species and survey expertise was established and initiatives were put in place to consider and improve the management of marine ecosystems. The Palau National Invasive Species Committee is very pro-active and involved in further initiatives across the Pacific island region (http://www.palaunisc.org/news--noteworthy/archives/06-2016).

Based on dialogue during the workshop and outcomes of the field survey, the following recommendations were made to the OERC and various State Governments to improve introduced marine species management in Palau:

1. An evaluation of the roles and responsibilities of national and state governments for marine biosecurity delivery needs to occur;
2. A full baseline port survey, including regions beyond Koror State, should be implemented to gauge the presence of introduced and cryptogenic species that may cause high risk impacts to economic, cultural, social and environmental values. The preliminary findings suggest that commercial and non-commercial vessel areas (e.g., tourist destinations) are a high priority. We note that since the initial sampling reported here,

additional sampling has started to occur and is ongoing (I. Olkeriil, pers. comm.). However, the recommendation that a full baseline port survey be conducted has not been acted upon;

3. Risk assessments should occur to determine high risk routes (pathways), and transport vectors into Palau and into different Palau islands. By understanding the pathways and vectors of introduced species effective management strategies can be formulated;
4. A risk assessment of high risk species that pose a future threat to Palau should be conducted to aid in the creation of effective preparedness plans that include targeted surveillance, with rapid response plans (also see points 6 and 7);
5. A programme for inspection of high risk vessels (based on risk assessments) entering Koror State should be considered. Consideration of domestic borders and pathways should also occur;
6. An action plan that details how the detection of an introduced species should be dealt with and delineates the government agencies that are responsible for different tasks within the action plan should be developed;
7. Eradication and management plans for a number of potential high risk species should be developed for rapid implementation in the likelihood that a high risk introduced species is detected; and
8. Mooring buoys and ropes at tourist destinations need to be changed frequently to prevent the transfer and establishment of introduced species between tourist locations.

For a number of reasons, including limited resources, most of these recommendations have had no, or only partial, implementation. Palau continues to explore avenues for obtaining resources for this purpose.

It should be noted that a Regional Biosecurity Plan (RBP) for Micronesia and Hawaii has been developed and adopted in association with build-up of US Government resources in Guam. The assessment for the RBP evaluated both direct and regional risks and impacts across terrestrial, freshwater and marine systems and included several elements of the recommendations listed above in the marine assessment (Ruiz et al. 2015) The Strategic Implementation Plan (SIP) for the RBP outlines numerous activities for implementation of the plan; activities specific to Palau include a number of marine-related activities, including development and adoption of hull fouling regulations, and building capacity to enforce such regulations.

Conclusions

Palau is a pristine destination that attracts a large number of international tourists; however introduced marine species are becoming prevalent in this region, which could have economic implications for tourism. The Palau government is pro-actively attempting to prepare for the impacts that may be associated with introduced species. As part of this preparation, an introduced marine species capacity building exercise that combined both theory and field experience was implemented within Koror State. This was managed via a workshop that trained 10 Palau and two international agencies in introduced marine species and port survey techniques. The survey and subsequent literature review detected 11 introduced, two cryptogenic and seven potentially introduced species. A series of recommendations were made to aid Palau in its ability to prepare and deal with introduced marine species. This work is preliminary in nature and continued efforts on introduced species management are needed to ensure Palau is fully prepared for this global problem of introduced marine species.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Pre-existing knowledge of introduced and cryptogenic species in Palau, Guam, Western and American Samoa, and tropical Australia.

Appendix 1. Taxonomic databases and networks (listed alphabetically).

Appendix 2. Taxonomic bibliography.

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