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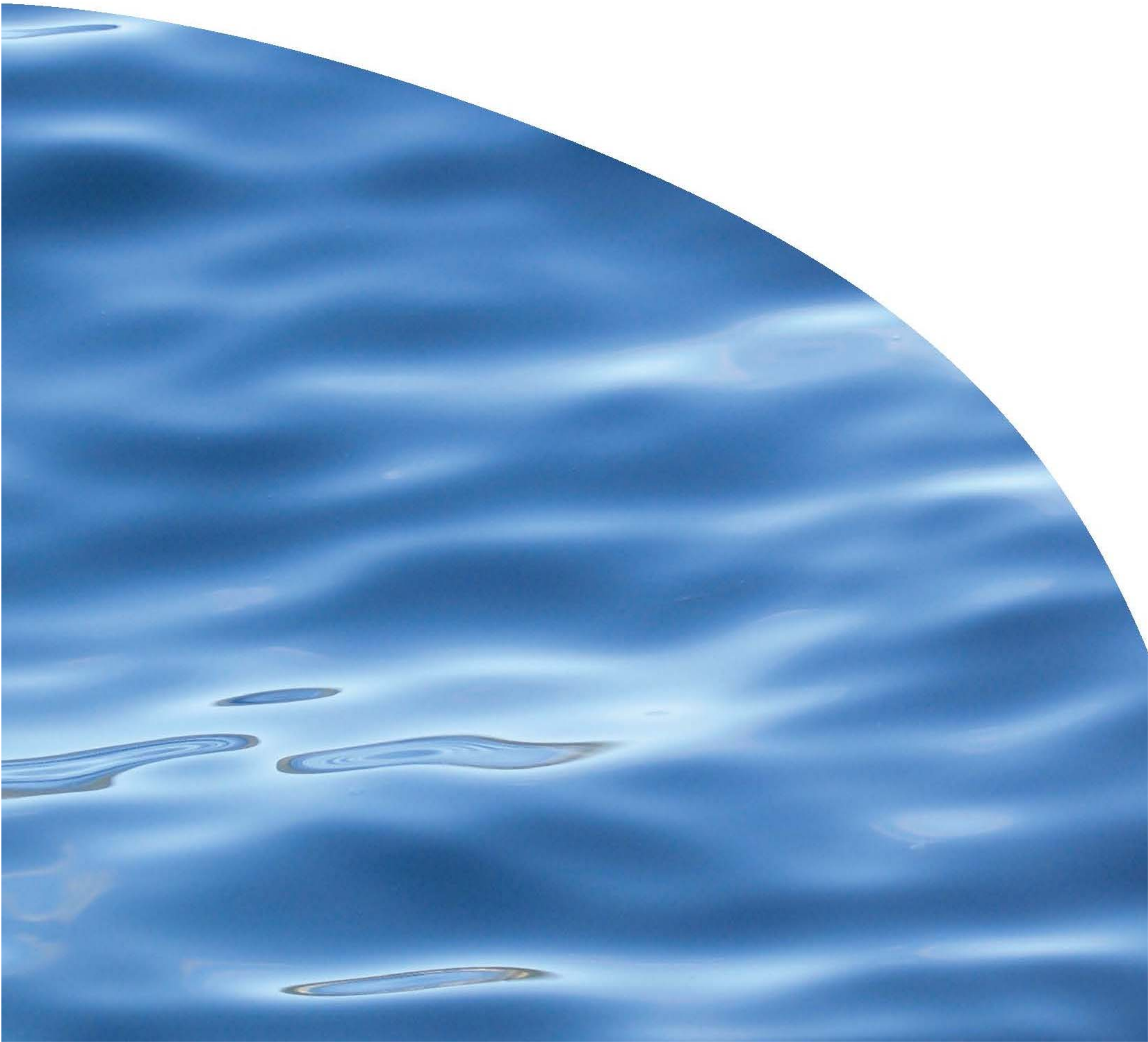
BACKGROUND INFORMATION ON THE SEA SQUIRT *PYURA DOPPELGANGERA* TO SUPPORT REGIONAL RESPONSE DECISIONS



BACKGROUND INFORMATION ON THE SEA SQUIRT *PYURA DOPPELGANGERA* TO SUPPORT REGIONAL RESPONSE DECISIONS

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EXECUTIVE SUMMARY

The non-indigenous solitary sea squirt, *Pyura doppelgangera* (herein *Pyura*), was first detected in New Zealand in 2007 after a large population was found in the very north of the North Island. A delimitation survey by the Ministry for Primary Industries (MPI) during October 2009 found established populations at 21 locations within the region. It is not known how long *Pyura* has been present in New Zealand, although it is not believed to be a recent introduction. *Pyura* is an aggressive interspecific competitor for primary space. As such, this species may negatively impact native green-lipped mussel beds present, with associated impacts to key social and cultural values. Based on the delimitation survey findings, it was determined that fully eradicating *Pyura* was not feasible. However, localised elimination was considered possible from some high-value sites where population numbers were relatively low. A 3-stage pilot treatment programme was carried out by MPI between August 2010 and August 2011 to assess the feasibility of removal efforts.

Cawthron Institute (Cawthron) was commissioned by Marlborough District Council (MDC) under the Ministry of Science and Innovation's Envirolink medium advice grant scheme to conduct a desktop assessment of key technical information relating to this species, and provide an evaluation of the invasion potential and considerations for management within the Marlborough region. Information regarding *Pyura*'s biology, likelihood of establishment, potential for further spread, and impacts to key values will enable effective decision making around any future eradication or containment efforts. The key findings of this review into *Pyura*'s biology and ecology are summarised below:

- *Pyura* shows specific habitat preferences, often forming large aggregations on rock platforms within the low-mid intertidal zone and shallow subtidal.
- Populations are often affected by wave disturbance and can be limited by smothering through sand movement.
- Spawning in *Pyura* populations may be initiated and synchronised by tidal cycles (closely related species spawn when exposed to air). This may be an adaptive mechanism to increase fertilisation success.
- Larvae are likely to be gregarious (new recruits often found in clusters and growing on adults) which may lead to retention close to parent populations.
- Populations can possibly survive in most coastal regions of the North Island as well as the top of the South Island (based on temperature profiles in the native range).
- *Pyura* can be considered an ecosystem engineer species; populations can considerably alter community structure within an area.
- Populations are likely to only spread short distances through natural dispersal alone. Propagules are believed to spend ~12 hours in the water column.
- There is also potential for human-mediated spread through hull fouling and the transfer of aquaculture stock and equipment.

Effective management of marine pests after they have been detected in a location is often challenging and expensive. Generally, any management programmes that are initiated in response to incursions need to have a high likelihood of success because of competing funding priorities. Successful invasive species management in the marine environment is largely reliant on the species having:

- limited natural dispersal potential
- low fecundity
- specific habitat requirements
- conspicuous morphology and visible individuals.

Pyura appears to meet these requirements relatively well. This species pelagic larval duration of ~12 hours means spread through natural dispersal alone is likely to be limited. In addition, the synchronous spawning behavior exhibited and the gregarious nature of sea squirt larvae means retention of propagules close to the parent population is likely. This species shows a preference for open environments, especially exposed rock platforms. As such, habitats at risk within a region can be identified easily, particularly those close to vessel hubs and sources of human-mediated spread. Lastly, the tendency of this species to form large aggregations of individuals means populations are more likely to be detected than those of small, cryptic species. Difficulties will still arise with regards to detection of newly settled or small individuals however.

Critical information gaps with reference to *Pyura*'s introduction to new regions include reliable information around potential impacts to both environmental and economic values. *Pyura* is an aggressive interspecific competitor for primary space and has the potential to considerably alter intertidal community structure and composition. In New Zealand, dense mats of *Pyura* have already engulfed and displaced native green-lipped mussel beds in some areas of the far North (Hayward & Morley 2009). The New Zealand mussel industry is heavily reliant on wild-caught spat from this region. As such, research into its impact on mussel reefs in Northland is needed, until which the degree of risk from *Pyura* remains unknown. Consideration of a worst-case scenario, *i.e.* significant adverse effects on the regions aquaculture and environmental values, would be prudent when making decisions on whether, and to what extent, to respond to any future *Pyura* incursions.

The most feasible control method for this species is removal by hand. Although this method is time-consuming it has shown promising results at treated sites in the far North (Jones *et al.* 2012). Recolonisation of cleared areas by *Pyura* appears to be gradual, particularly in areas where the population is isolated from additional sources of recruitment. As such, any sustained and intensive population control efforts for new incursions show a good likelihood of success. As with the pilot treatment programme, surveillance and removal efforts will need to be frequently repeated in the initial stages of any management programme. The intertidal habitats of *Pyura* populations will make eradication efforts easier and less expensive than those for subtidal species. Specialised contractor services are required for diver-based management efforts, which can also be logistically more challenging due to affordability of search time, lower detection limits and the requirement for specialised staff.

Consideration should be given to preventing or slowing the spread of *Pyura* to high-value areas (*e.g.* key aquaculture regions or marine protected areas). The development of pathway management plans between regions is an important component of invasive species management, but will require a collaborative approach between neighbouring regions and central government. Although challenging, this may provide the best value for money in the event of multiple incursions or the presence of more than one target species within the region (*e.g. Styela clava*'s recent detection in Picton).

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1. INTRODUCTION

Introduced marine pests pose an important long-term threat to coastal ecosystems within New Zealand. In addition to biodiversity loss and the alteration of ecosystem function, the introduction of a marine pest to a region and associated response efforts can result in considerable economic costs. The last 10–15 years has seen an increased prevalence of invasions and adverse effects from marine pest species in New Zealand, particularly with reference to high-value industries such as shellfish aquaculture. Negative impacts to key cultural and amenity values are also possible (*i.e.* impacts on food harvesting, tourism, recreational fishing).

Effective management of marine pests after they have established in a location is often challenging and expensive. Generally, any management programmes initiated to deal with such incursions need to have a high likelihood of success due to competing funding priorities. A thorough understanding of a species biology and ecology, particularly in relation to invasion and spread potential, likelihood of establishment and options for control is crucial to this process. For example, an understanding of natural dispersal potential is of particular importance as this underpins a number of common management needs. This includes identification of the spatial scales for vector control, as well as delimitation zones for surveillance. The natural dispersal ability of biofouling species can vary considerably, with vessels and other anthropogenic vectors often playing an important role in extending the spatial scale and rate of species spread. Simultaneously, knowledge of actual and potential impacts provides a critical context for prioritising and optimising management approaches. For example, this provides insight into the effort required to reduce invasion levels to a point where density-dependent effects are mitigated. The ability to make well-informed decisions with regard to associated costs and benefits will enable timely response actions where necessary, as well as prevent futile expenditure where eradication or management is not feasible.

Pyura doppelgangera (herein *Pyura*) is an intertidal species of solitary sea squirt which has been introduced to New Zealand coastal environments. This species is well established in Tasmania and south-eastern Australia, and has recently been discovered in northern New Zealand. *Pyura* was first detected in New Zealand in 2007, in the far north of the Northland region (Hayward & Morley 2009). This population has subsequently become well established, with populations identified at several additional locations on both the west and east coasts of the far North region. At present, *Pyura* is not believed to be established in the Marlborough region. *Pyura* has the potential to strongly alter resident intertidal benthic community structure because of its tendency to form dense aggregations. This species is likely to compete with native organisms for both food and space resources. Although *Pyura* is not formally recognised as an 'unwanted organism' under the Biosecurity Act 1993, MPI have identified a number of core values at threat from the presence of this species in New Zealand (MPI 2014).

Due to concerns around the further spread of *Pyura* within New Zealand, Cawthron Institute (Cawthron) was commissioned by Marlborough District Council (MDC) under the Ministry of Science and Innovation's Envirolink medium advice grant scheme to:

- Provide background technical information on the biology, vectors of spread, and ecological and economic impacts of *Pyura.*
- Assess the invasion potential and management options for *Pyura* within the Top of the South region.
- Identify any critical information gaps with reference to species biology, impacts and management options.

In addition to regional responsibilities, MDC is a member of the Top of the South (TOS) Marine Biosecurity Partnership, which was formed in 2009 with the objective of improving marine biosecurity management. The Top of the South region encompasses the coastal areas administered by MDC, Nelson City Council and Tasman District Council. The information provided in this report will be make an important contribution to the goals of this Partnership, in particular the identification and clarification of key needs for pathway risk reduction efforts, which is presently a priority work area of the Partnership. Similarly, the information provided will assist other regional councils should there be incursions of *Pyura* in other regions.

This report summarises technical information for *Pyura* drawn from New Zealand sources when possible, supported by overseas information where necessary. Due to this species relatively recent arrival in New Zealand, the majority of research on key biological and ecological characteristics has been carried out overseas.

2. TECHNICAL INFORMATION ON *PYURA*

2.1. Identification history and related species

Confusion around species identification has led to several name changes for the species present in New Zealand. Following discovery in 2007, the species present in Northland was believed to be *Pyura praeputialis* (also known as 'cunjevoi' in its native Australia). *Pyura praeputialis* is a large and highly conspicuous sea squirt, and is often a dominant member of the lower intertidal and shallow subtidal fauna present in southern Australia.

The existence of a small form of *P. praeputialis*, with a distribution centred around Tasmania (and more recently northern New Zealand), has long been known (*e.g.* Kott 1985). However, both forms have traditionally been treated as a single species due to their morphological similarity (Rius & Teske 2013). Recent genetic and morphological analyses have provided conclusive evidence the small and large morphs of *P. praeputialis* are in fact two separate species (Astorga *et al.* 2009; Rius & Teske 2013). As such, the smaller morph (which is the species present in Northland) has been formally described as a new species and named *Pyura doppelgangera* (Rius & Teske 2013).

Pyura doppelgangera is a member of the '*Pyura stolonifera* species complex', which includes at least five species of large, solitary ascidians that are all often incorrectly referred to as *P. stolonifera* in literature (Teske *et al.* 2011). Species within this group are all found within temperate rocky-reef communities, with habitat ranges across South America, South Africa and Australasia (Teske *et al.* 2011; Rius & Teske 2013). At present only *P. doppelgangera* is present in New Zealand. All five species share certain morphological characteristics, such as cross-shaped siphon openings and the absence of atrial tentacles on the exhalent siphon, however differences in a number of internal characteristics can be used for diagnostic purposes (Rius & Teske 2013).

There are other species of sea squirts from the Pyuridae family present in New Zealand. A separate species complex of native pyurid sea squirts has been recognised (Page *et al.* 2013), with these species relatively common throughout both the North and South islands. These species looks quite different to the introduced *Pyura* however. They are subtidal, primarily found growing on the seabed attached to shell debris and fouling wharf piles, and do not form extensive aggregations. For the purpose of this report the term *Pyura* will refer to *P. doppelgangera*, although there are instances where relevant information on *P. praeputialis* or *P. stolonifera* is discussed. Due to the close similarities between species, the biological and ecological characteristics described are likely to be comparable to those shown by *Pyura*.

2.2. Distribution and invasion history

2.2.1. Native distribution

Pyura is native to Australia with its distribution centered around Tasmania (Kott 1985; Fairweather 1991; Dalby 1995). It has also been reported from South Gippsland, Victoria (Port Welshpool and Port Albert) and South Australia (Adelaide) (Rius & Teske 2013). The larger *P. praeputialis* shares the same native range. *P. praeputialis* is widely distributed throughout south-eastern Australia, with populations along the Victorian and New South Wales coastlines. Although the ranges of these two species overlap on mainland Australia, to date *Pyura* has only been found in areas where *P. praeputialis* is not present (Rius & Teske 2013).

2.2.2. Worldwide distribution

Currently the only known populations of *Pyura* are within the native range of Australia and the introduced range in northern New Zealand. The closely-related species *P. praeputialis* has established a single invasive population in northern Chile.

2.2.3. Introduction and distribution in New Zealand

Pyura was first detected in New Zealand in 2007, when it was found growing on rocks near Cape Maria van Diemen, in the far north of the Northland region (Hayward & Morley 2009). This population has subsequently become well established, with populations found at 21 sites over an estimated 97 km of rocky coast during an initial delimitation survey in 2009. A further four locations were reported in the two years since the delimitation survey. Established populations have now been identified on Twilight and Te Werahi beaches near Cape Reinga; around The Bluff on Ninety Mile Beach and the Tauroa Peninsula; at Whareana Bay, Tokatoka Point and at three locations within Parengarenga Harbour. Further south, it has been found at Mitimiti and Omapere (near Hokianga Harbour) on the west coast, as well as at Rangiputa and in the Houhora Harbour on the east coast (MPI 2014). The most recent confirmed significant range expansions are to Orongo Bay and Okiato Point, both in the Bay of Islands (Figure 1). *Pyura* was found on an oyster farm in Orongo Bay. The population at Okiato Point (adjacent to Opua marina) was found during routine MPI-funded ‘Marine High Risk Site Surveillance’ in November 2013 (pers. comm. G. Inglis, National Institute of Water and Atmospheric Research).

The vector for *Pyura*’s introduction to New Zealand remains unknown. The locations of the first records do not provide conclusive support for the hypothesis of introduction as fouling on boats. The far North region is a very exposed and remote section of coastline and there is no commercial port nearby (Hayward & Morley 2009). It is possible that a vessel fouled with *Pyura* passed sufficiently close to the west coast area (the presumed location of the founder population) and there was a spawning event, or that a fouled vessel came ashore or was wrecked there. There is also a possibility the species was introduced via natural dispersal of adults attached to floating debris from Tasmania or southern Australia. Recent genetic analysis showed all individuals sampled from New Zealand share a common allele, indicating loss of diversity through genetic drift or a strong bottleneck effect (Teske *et al.* 2011). It is not known how long *Pyura* has been present in New Zealand, although it is not likely to be a recent introduction based on the extent and maturity of populations found in the Northland region. Anecdotal reports from local communities suggest it had been present on the Tauroa Peninsula for at least 10 years prior to formal identification and at The Bluff for less than five years (Jones 2010).

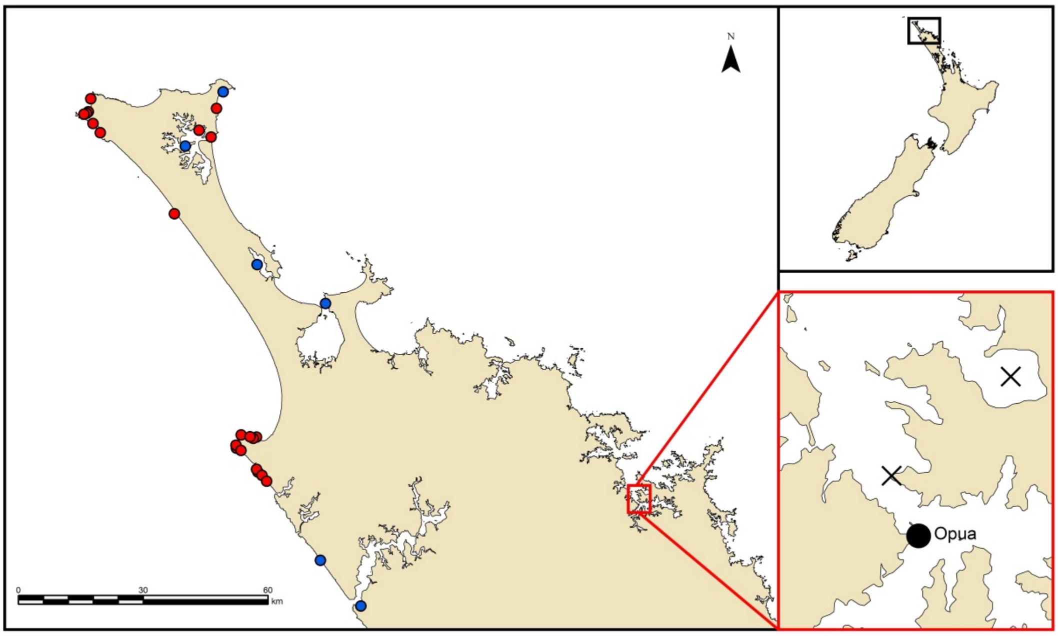

Figure 1. Map of known *Pyura* populations within the Northland region of New Zealand. *Red circles* = delimitation survey (October 2009). *Blue circles* = populations reported between August 2010 and March 2014. *Black crosses* = incursions at Okiato Point and Orongo Bay within the Bay of Islands.

2.3. Biology and natural history

2.3.1. Body structure

Pyura are sessile, with the animal encased in a tough, leathery outer case or ‘tunic’. This outer tunic is generally brown or reddish-brown in colour, and sand and shell material is often embedded into the structure (Figure 2). In most instances there is other sea life, such as sea lettuce, growing in and around the individuals. *Pyura* individuals are somewhat squat in appearance and are smaller than the closely related species *P. praeputialis*. The formal description of this species by Rius and Teske (2013) reported a height range of 25–50 mm and a width range of 15–35 mm.

However, larger adult *Pyura* have been found at some sites in Northland (including The Bluff and Parengarenga Harbour). Adults from Twilight Beach been documented at 100–150 mm height and 30–50 mm width (Hayward & Morley 2009). Maximum diameters are often influenced by the degree of aggregation among populations and subsequent crowding effects. Each individual has two siphons or holes for inhaling and exhaling water. When disturbed the organism rapidly retracts these siphons using strong longitudinal muscles located beneath the protective outer tunic.

Beside differences in maximum body size, *Pyura* is externally indistinguishable from *P. praeputialis*, with identification only possible through dissection and comparison of internal structures (Rius & Teske 2013). Following removal from the tunic, the body wall is generally dark purple but it can be orange in some specimens. The siphons are always dark violet; however there is generally a gradient of colours ranging from orange to purple around the siphons. Internal characteristics distinguishing this species from the other members of the species complex include: the dorsal tubercle is smooth; the anus has no defined lobes; the digestive track does not have a secondary gut loop or it is short and never curves sharply; and the gonoduct on the left side is clearly separated from the anal aperture (Rius & Teske 2013).

Figure 2. *Pyura* individuals growing on rocky-reef substrate at The Bluff, on the west coast of the far North. Note that most individuals have their siphons retracted. Photo courtesy of Roger Grace.

2.3.2. Feeding and filtration

Like all sea squirt species, *Pyura* is a ciliary-mucus filter feeder, consuming primarily phytoplankton, suspended particulate matter, diatoms and suspended bacteria

(Lambert 2005). A mucus net or mesh-like structure is continuously secreted, with incoming particles becoming entrapped. These mucus-bound particles are then gathered and transported to the oesophagus and the stomach that lie below the branchial sac. Material passes into the intestine and the faeces are discharged into the atrial cavity after which they are expelled through the exhalent siphon. Sea squirts are particularly efficient at retaining very small particles (< 2 µm) such as bacterioplankton or picoplankton (Bone *et al.* 2003), although they do ingest larger particles including their own gametes (Lambert 2005). Unlike bivalves, they lack the capacity to sort particles and reject unsuitable material as pseudofaeces. Instead, as particle concentrations increase they exhibit an increased frequency of 'squirting', or muscular contractions, which actively expel accumulated material through the inhalant siphon and prevent clogging of the branchial sac (Carver *et al.* 2006).

Specific information on the food preferences, filtering capacity and feeding efficiency of *Pyura* is not available. However, research on this topic has been carried out for *P. stolonifera* populations in South Africa. This species has been demonstrated to retain particles in the size range 0.5–20 µm with 100% efficiency, representing 80% of the volume of natural suspended matter (Stuart & Klumpp 1984). As discussed above, high silt loads or high density of large-sized particles (> 65 µm) resulted in 'squirting' (Klumpp 1984). Previous studies indicate that sea squirts are able to process large volumes of water. *P. stolonifera* from open coast environments were found to have a filtration rate[1] of ~8 ml per minute per gram of dry tissue weight (Klumpp 1984). An average sized individual of 4 g dry weight would therefore be able to filter ~46 L of sea water per day.

Pyura praeputialis has been found to enhance suspension feeding rates by inducing passive flow. In this species the inhalant siphon is directed horizontally while the exhalant siphon is higher and directed vertically. Individuals were found to be consistently orientated with their horizontal-facing inhalant siphon directed into oncoming waves. This orientation resulted in individuals gaining food at greater rates, as measured by fecal production, than when oriented perpendicular to the wave direction (Knott *et al.* 2004).

2.3.3. Reproduction and development

Knowledge of reproductive strategies and seasonal development is of particular importance in formulating effective management strategies. The reproductive biology of many solitary sea squirts has been well documented; however, there does not appear to be any published information on the reproduction and development of *Pyura* specifically. A thorough review of early embryology, larval development and metamorphosis for *P. praeputialis* populations in Chile and Australia has been conducted (Anderson *et al.* 1976; Clarke *et al.* 1999).

[1] The volume of water cleared of particles in unit time.

Species within the *Pyura* complex are hermaphroditic (individuals possess both male and female reproductive organs), and are believed to be self-fertile (Anderson *et al.* 1976; Clarke *et al.* 1999). The production of eggs and sperm is simultaneous. The maturity of adult specimens can be determined visually through dissection, and confirmed using a microscope. Specimens are first removed from the outer tunic or test and opened to expose the gonads; olive-green swollen or distended ovaries and white-yellow testes are considered evidence for sexual maturity (Clarke *et al.* 1999). Mature eggs are spherical, olive-green and approximately 240–310 µm in diameter (Clarke *et al.* 1999). *Pyura* reproduce through broadcast spawning, with both eggs and sperm being expelled through the atrial siphon into the water column.

Following release of the gametes, fertilisation and embryo development occurs within the water column. The lecithotrophic (non-feeding) tadpole larvae 'hatch' out of the membrane layer approximately 12 hours after fertilisation (although this can be up to 18 hours). The free swimming larval stage has been recorded to last between 1–3 hours under laboratory conditions before they settle (Anderson *et al.* 1976; Clarke *et al.* 1999). Larvae are believed to be gregarious, and recently settled individuals are often found in clusters as well as growing directly on adult specimens (Paine & Suchanek 1983). Metamorphosis into the early juvenile stage usually occurs within 2–3 days after fertilisation. The juvenile is transparent at this point, with a pigmented circle around the tip of the siphons appearing after seven days, and the tunic turning opaque at least nine days after fertilisation (Clarke *et al.* 1999).

The reproductive cycles and timing of spawning in sea squirts is often determined by local environmental conditions, particularly water temperature or photoperiod (Fletcher *et al.* 2013). Spawning is generally dependent on seawater temperatures achieving a critical threshold. Once individuals reach maturity gametes are produced continually as long as temperatures are suitable. Analysis of *Pyura* specimens collected from Northland during early spring (August / September) suggested that the individuals were reproductively mature at this time (Jones *et al.* 2012). No specific information on temperature thresholds for the initiation of spawning, or reproductive season duration is available.

Pyura praeputialis populations in Chile and Australia show variable reproductive cycles. Analysis of gonad development showed evidence of two spawning seasons per year (spring and autumn) for one Australian population (Goddard 1972). In contrast, reproductive maturity during the spring and summer has been suggested for another Australian population. Gonad indices were shown to be highest over this period, with reductions through summer and autumn (Dalby 1996). Populations in Chile are believed to be mature from March through to December (autumn through to spring in the Antofagasta region) (Clarke *et al.* 1999).

Spawning in *P. praeputialis* is believed to be initiated and synchronised by air exposure, as spawning is often observed to occur once individuals become exposed during low tides (Manriquez & Castilla 2010). This may be an adaptive mechanism to increase fertilisation success. By spawning at low tide, the exposure of gametes to the turbulent waters typical of the rocky intertidal is minimal, thereby reducing dilution and advection of gametes. After spawning, the gamete suspensions often seep into the gaps and pools between adjacent specimens, with these microhabitats providing ideal conditions for successful fertilisation (Meidel & Yund 2001). The incoming tide further enables fertilisation, particularly when individuals are isolated from others. Fertilisation success has been shown to decrease rapidly with distance when the nearest spawner is parallel to the shoreline, but decreases more slowly when the nearest spawner is perpendicular to the shoreline (*i.e.* in line with the path of waves) (Marshall 2002). These synchronous spawning events of *P. praeputialis* often lead to the development of large bio-foams, which are also believed to enhance fertilisation success as well as increase the retention of larvae in rocky shore environments (Castilla *et al.* 2007).

2.3.4. Growth and reattachment time

Growth rate data for *Pyura* is limited and no information is available for the population in New Zealand. A growth rate of 20–30 mm in height per year has been recorded for *P. praeputialis* near Melbourne, Australia (Dalby 1995).

Individuals are able to reattach to the substrate through the secretion of a substance from the ventral surface that facilitates adhesion. However, individuals need to be secured in place for reattachment to be successful; a process takes ~1 month under field conditions (Dalby 1995; Caro *et al.* 2011).

2.3.5. Habitat and environmental tolerances

Pyura populations generally inhabit the low-mid intertidal zone, as well as shallow subtidal areas in some regions (< 12 m depth). In New Zealand, *Pyura* colonises rocky platforms and outcrops, rock pools and the underside of rock overhangs (Jones *et al.* 2012). Populations often form large mats that completely cover considerable areas of rock platforms (*e.g*. Figure 3). Population abundance generally decreases with depth. Aggregations are often in very exposed areas with strong wave action (Hayward & Morley 2009; Jones 2010). Intertidal wave energy has been suggested as one of the enhancing factors permitting the existence of higher suspension-feeder biomass on exposed than on sheltered rocky shores (MacQuaid & Branch 1985; Leigh *et al.* 1987). However, this high-energy environment can also be limiting. Populations are frequently disturbed by wave action, often leading to the complete removal of large aggregations. Surveys of *P. praeputialis* populations in Chile found a ~70% reduction in percent cover following disruption by a major storm in 1976 (Paine & Suchanek 1983). Populations also appear to be limited by sand movement within an area and the subsequent smothering of the *Pyura* beds. A large and dense population at Parengarenga Harbour entrance has now disappeared. This is most likely due to a large number of easterly onshore conditions smothering them with fine sand (pers. comm. K. Walls, Ministry for Primary Industries).

Pyura extensively colonise natural substrates in both Tasmania and northern New Zealand, however this species is found exclusively on artificial structures in Victoria and South Australia (Rius & Teske 2013). The distribution ranges of *Pyura* and *P. praeputialis* overlap in Victoria; however, the two species have not been found growing together. The two species show differing habitat preferences in this area. *P. praeputialis* often forms large aggregates in exposed areas, while *Pyura* shows a preference for artificial substrates in sheltered locations. It has been suggested that this difference in habitat preferences may indicate that *Pyura* has recently been introduced to mainland Australia, where it has subsequently established itself in habitats where *P. praeputialis* is absent (Rius & Teske 2013).

Figure 3. *Pyura* aggregations within the intertidal zone at the entrance to Parengarenga Harbour. Photo courtesy of Kathy Walls (MPI).

Specific reports of temperature and salinity tolerances for *Pyura* are not available. Although currently only present in the far North of New Zealand, temperature profiles within its native range of Tasmania indicate survival is possible in most coastal regions of the North Island and the top of the South Island. Average sea surface water temperatures in Hobart, Tasmania, are lowest in August (~12.6 C). This is similar to lowest monthly averages recorded for Picton, New Zealand (~12.3 C) (WST 2014). *Pyura* populations are likely to be limited by colder sea water temperatures further south, and may not survive winter temperatures in other regions of South Island. Populations are already established in the most northern region of New Zealand, so this species is unlikely to be limited by high sea water temperatures elsewhere. Sea squirts can generally tolerate a wide salinity range with species often recorded from brackish systems with salinity levels as low as 26 PSU[2]. *Pyura* is not able to tolerate freshwater immersion. Laboratory experiments found exposure of *P. praeputialis* to 23.5 PSU for 40 minutes caused a total cessation of filtration. Furthermore, recovery of filtration was not observed over the course of the experiment (200 minutes), and some animals later died (Evans & Huntington 1992). Similarly, river run offs and flooding have been shown to kill *P. stolonifera* populations living at shallow depths in South Africa (Branch *et al.* 1990).

2.3.6. Ecology and population dynamics

Although *Pyura* is technically a solitary species (as opposed to colonial), adjoining individuals are cemented together and very difficult to pry apart (Paine & Suchanek 1983). As such, aggregations of individuals achieve a collective unity or pseudo-coloniality which may lead to particular competitive advantages. Aggregations of *Pyura* can be very extensive often covering large portions of the intertidal zone. In Chile, *P. praeputialis* densities of > 1,800 individuals per m^2 have been recorded at the center of the Bay of Antofagasta (Castilla *et al.* 2000).

Pyura can be considered an ecosystem engineer species, serving as a secondary substrata for settlement by conspecifics and algae (*i.e.* the prevalence of sea lettuce associated with *Pyura* beds), and providing microhabitat for many invertebrates (Cohen *et al.* 2000). In Chile, *P. praeputialis* provides habitat for at least 96 species of macroinvertebrates and 20 species of macroalgae at the mid-low intertidal fringe in Antofagasta Bay (Castilla *et al.* 2004a). Dense beds of *P. praeputialis* also dominate shallow-water sites along the eastern coast of Australia, providing habitat for 45 macroinvertebrate and 19 algal species. This species richness was ~50% higher than equivalent rocky intertidal fringes outside of the bay (Monteiro *et al.* 2002; Castilla *et al.* 2004a)). Without *P. praeputialis* beds most of these species are restricted to lower intertidal environments (*e.g.* under boulders, in crevices, within holdfasts of macroalgae), or in the subtidal zone (Castilla *et al.* 2004a). The abundance of associated invertebrate species may aid in the spatial dominance of *P. praeputialis*. Large algae are often absent from areas with well-established *P. praeputialis* beds which may be due to competitive elimination by the associated community of mobile grazers (*e.g*. chitons, limpets, urchins) (Paine & Suchanek 1983).

2.3.7. Predators

In New Zealand, the native sea star *Stichaster australis* has been observed predating on the *Pyura* population at The Bluff (Figure 4). A whelk within the genus *Cabestana* has also been observed predating on *Pyura* on the Tauroa Peninsula (pers. comm. K. Walls, Ministry for Primary Industries).

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[2] Practical salinity units

Predation of *P. praeputialis* in Victoria, Australia, has been documented for a range of species, including gastropods, crabs, asteroids, rays and eels (Dalby 1995 and references therein). *Pyura praeputialis* in Chile are eaten by at least five species. Three species of gastropods feed on both the detached and subtidal clumps. One species in particular, the Chilean abalone (*Concholepas concholepas*), has been implicated as a major subtidal predator of *P. praeputialis*. This gastropod feeds on relatively large individuals by either boring through the tunic or inserting its proboscis through one of the siphons (DuBois *et al.* 1980; Paine & Suchanek 1983). Within the intertidal zone, two species of sea star are believed to be the most significant predators, and predominantly consume smaller (< 5 cm diameter) individuals within the Antofagasta region. Their initial method of penetration is believed to be through the siphonal openings (Paine & Suchanek 1983). Predation on juvenile *P. praeputialis* by starfish and snails has been suggested as a regulatory mechanism for tunicate population structure at lower intertidal zones (Castilla *et al.* 2004b).

Figure 4. Native seastars (*Stichaster australis*) feeding on *Pyura* populations. Photo courtesy of Roger Grace.

A species of wading bird, the sooty oystercatcher, also feeds on intertidal *P. praeputialis* populations in both Australia and Chile. This bird has been shown to feed on attached sea squirts during low tides and on wave-dislodged sea squirts during high tide. The oystercatchers attack the attached individuals on the top of their tunic, perforating the area near the siphon. Wave-dislodged individuals are also punctured, however in this instance up to four holes are made and these are mainly on the side of the tunic (Pacheco & Castilla 2001). The sea squirt represents an important food resource for the bird (Chafer 1992).

2.4. Human uses

Although not harvested commercially, *Pyura* in Australia are commonly gathered by recreational fishers, who use the fleshy animal inside as bait (Fairweather 1991). In South Africa, collection of *P. stolonifera* for bait is a commercial enterprise, yielding up to 30 tonne per annum (Fairweather 1991 and references therein). There has been concern that the effects of harvesting may deplete *P. praeputialis* populations within its native range, however, at present the species remains abundant and is not considered under threat. As a significant proportion of populations are located in inaccessible areas (*e.g.* rocky outcrops in high-energy surf zones), any depletion is likely to be localised. A bag limit of 20 individuals is also in place for recreational harvest of this species in New South Wales (Rowling *et al.* 2010).

A closely related species, *Pyura chilensis* is harvested commercially in Chile (Davis 1995). Fishermen typically cut *P. chilensis* into slices with a handsaw, and then use their fingers to pull out the internal structure from the tunic, which is then discarded. The flesh is usually sold in strips, but may be canned. It is exported to numerous countries including Sweden and Japan.

2.5. Natural and human-mediated pathways of spread

It is important to understand the natural dispersal potential of invasive species as this underpins a number of common management needs. This includes identification of the spatial scales for vector control, as well as delimitation zones for surveillance (*e.g.* Forrest *et al.* 2009). As many biofouling species have a limited natural dispersal ability, vessels and other human-mediated vectors can play an important role in greatly extending the spatial scale and rate of species spread. An understanding of human-mediated spread helps to define locations at risk, as well as key vectors that should be targeted as part of management efforts.

2.5.1. Natural dispersal

As adult *Pyura* are sessile organisms, the primary method of natural dispersal for this species is the transportation of larvae by water currents. Information on the natural dispersal ability of *Pyura* is not available however several studies have been conducted on the early life-stages of *P. praeputialis*. Following external fertilisation, *P. praeputialis* embryos spend between 10–18 hours (generally ~12 hours) in the water column before hatching as tadpole larvae (see Section 2.3.3). In Australia, these tadpole larvae have been shown to have an active free-swimming period of between 1–2 hours (Anderson *et al.* 1976). Similarly, larvae of the same species from Chile were found to have a mean active free-swimming period of 2 hours 35 minutes (± 59 minutes) after being reared under laboratory conditions (Clarke *et al.* 1999). Assuming similar behavior for *Pyura* populations in New Zealand, there is a window of at least 12 hours during which offspring can be dispersed away from the parent population. This could lead to natural dispersal of relatively substantial distances depending on local hydrological conditions.

Long-distance advection is less likely when the many factors that limit true dispersal are considered (*e.g.* predation in the water column). Larvae reared in the laboratory will also not be exposed to natural settlement cues (*e.g.* physical and chemical habitat cues, light conditions encountered) which may extend the free-swimming period. In addition, the gregarious nature of sea squirts, whereby the presence of conspecific individuals (other larvae, juveniles or established adults) encourages further settlement of larvae within an area, may lead to retention close to their natal site (Rius *et al.* 2010). This localised retention may have important consequences in terms of the ability of populations to adapt to local habitat change and is likely to play a key role in the persistence of populations (Strathmann *et al.* 2002; Kawecki & Ebert 2004). As well as factors limiting dispersal distance, a wide range of post-settlement processes will also affect the successful establishment and persistence of populations. *Pyura* is likely to take many decades to spread through natural dispersal alone, particularly when natural barriers to spread such as long stretches of sand beach are considered (Hayward & Morley 2009).

2.5.2. Human-mediated spread

Like other fouling organisms *Pyura* is able to be transported rapidly around New Zealand as biofouling on a range of artificial structures. Intra- and inter-regional vessel movements, as well as aquaculture activities such as the transfer of equipment and shellfish seed-stock among growing regions, are likely to be the most important mechanisms for human-mediated spread. Translocation via ballast water from international shipping is not likely. *Pyura*'s pelagic larval phase of ~12 hours before settlement means larvae would not survive even short-term journeys in ballast tanks.

The species currently has a relatively isolated population range, so the importance of effective management of human-mediated spread cannot be underestimated. The recent detection of *Pyura* at Okiato Point (in the Bay of Islands) highlights this need. This location adjacent to Opua marina could lead to increased intra- and inter-regional spread through hull fouling, if not managed effectively. Prior to this detection, *Pyura* populations were largely located on remote areas of coastline with the potential infection of anthropogenic vectors in these areas somewhat reduced. The populations present on oyster farms in Parengarenga Harbour and more recently Orongo Bay pose could lead to human-mediated spread through the transfer of stock or equipment.

2.6. Impacts associated with introductions

Reliable information about impacts of *Pyura* infestations is critical to understanding the benefits of management. However, as is the case for most marine pests, the level of *Pyura*'s invasiveness and the associated adverse effects are difficult to determine reliably. This species can occur in high densities and could modify natural ecosystems through the possible competitive exclusion of native species. In very high densities it is likely to impact commercially important species including mussels and oysters.

2.6.1. Impacts on the environment

Pyura is an aggressive interspecific competitor for primary space. In the far North region *Pyura* has already created a new intertidal zone covered in dense mats of this species that has in places engulfed and displaced native green-lipped mussel beds (Hayward & Morley 2009). It has been suggested that new incursions of this species could result in a major restructuring of the native intertidal rocky shore ecology, almost as much as that caused by the introduction of the Pacific rock oyster (Hayward & Morley 2009). A similar change in zonation patterns was observed following the invasion of *P. praeputialis* to Antofagasta Bay in northern Chile. Recent experimental analysis of population dynamics within the bay found that *P. praeputialis* outcompetes native mussels (*Perumytilus purpuratus*) in the mid-low intertidal fringe, constraining mussels to the mid-upper zone. Juvenile and adult sea squirts encroach and grow successfully on the *Perumytilus* shells. Mussels subsequently became detached from the rock substratum. Growth rates are also reduced in those mussels which do survive encroachment by *P. praeputialis* (Caro *et al.* 2011).

Impacts to nutrient availability are also possible. The efficient removal of suspended organic particulates has the potential to change nutrient cycling and the microbial community. The high filtration rate of large aggregations of sea squirts can have a dramatic effect on available plankton and suspended organic matter at local scales (reviewed by Riisgård & Larson 2000). *Pyura* beds also increase species richness at local scales by providing a novel mid-intertidal habitat which is used by a range of macroinvertebrates that otherwise would remain excluded from this intertidal level (Castilla *et al.* 2004a). The presence of these species may alter trophic food webs within an area, which is likely to have localised impacts on other native species present. Habitat modification by *Pyura* may also facilitate the establishment of other invasive species, particularly those that are not usually found in the intertidal zone.

2.6.2. Impacts on industry

Pyura has not caused significant detrimental effects to marine industries in New Zealand with its present distribution. Little is currently known about the long-term risks posed by this species. There have been concerns around impacts to native green-lipped mussel beds in the far North (Northland Age, “Is this the end of mussels?” 2013), particularly as 80% of the industry is seeded from spat collected from 90 Mile

Beach. The mussel industry has been consulted and involved in decision making since the discovery of *Pyura* in the far North, and at present have not reported any significant impact from the presence of *Pyura* on spat collection within the region (Northland Age "MPI: We didn't miss the boat" 2013). Localised impacts on green-lipped mussel beds have been observed, and if left to spread, it is possible this species could affect traditional kaimoana[3] harvesting over large areas (MPI 2014). This species is able to colonise a range of hard substrates including artificial structures. It is therefore conceivable that *Pyura* could become a nuisance fouler on intertidal aquaculture systems such as commercial oyster leases. *Pyura* have been observed on hard substrates within muddy estuaries, often in and around oyster beds. Populations are currently established on two oyster farms in the far North, in Parengarenga Harbour and Orongo Bay; however, the farmers have not reported issues with it (pers. comm. K. Walls, Ministry for Primary Industries). This may be confounded by the recent oyster herpes virus outbreak which has severely impacted the industry in this area. The high biomass of problematic fouling organisms' increases the time and costs of harvesting, transporting and factory processing of cultured species. In addition, *Pyura*'s high filtering capacity may make it a competitor to cultured filter-feeding species such as oysters and mussels. *Pyura praeputialis* has been reported as impacting scallop culture in the Antofagasta region in Chile (Zapata *et al.* 2007).

[3] Seafood, shellfish.

3. CONSIDERATIONS FOR MANAGEMENT

Control and eradication of pest species in the marine environment is often technically and financially difficult (McEnnulty *et al.* 2001; Meyerson & Reaser 2002). Very few efforts to eradicate a marine species have ever been successful, with key exceptions being instances where arguably novel circumstances (*e.g.* the ability to close off an environment for treatment) have contributed to these successful management outcomes (*e.g.* Culver & Kuris 2000; Bax *et al.* 2001; McEnnulty *et al.* 2001; Wotton *et al.* 2004; Hopkins *et al.* 2011). If *Pyura* was to be detected in the Marlborough region, decisions regarding the feasibility of eradication or control will be necessary. To aid in this decision making, the history of *Pyura* control efforts in New Zealand, management techniques available, and considerations of the species invasion potential in the Top of the South region are outlined below.

3.1. Efforts to manage in New Zealand

The first record of *Pyura* in New Zealand was in May 2007 after a large population was found in the very north of the North Island. During a trip to the northern end of Twilight Beach, near Cape Reinga, a band of large solitary sea squirts was noticed by Dr. Bruce Hayward on the rocks exposed at low tide. Specimens were collected and confirmed as *P. praeputialis* by Dr. Mike Page, from the National Institute of Water and Atmospheric Research (NIWA) (Hayward & Morley 2009). In December 2008, Dr. Hayward spent a further two days documenting the extent of the population within the area. *Pyura* populations were found in three locations, the north and south ends of Twilight Beach and the west end of Te Werahi Beach (Hayward & Morley 2009).

In October 2009 a MPI-led delimitation survey was carried out, to assess the extent of the *Pyura* population within the greater Northland region. The survey covered an area extending from Herekino Harbour entrance northwards to Tarawamaomao Point, across the top of Northland and to the south of Rarawa Beach on the east coast (Jones 2010). *Pyura* was detected at 21 locations in the far North (Figure 1), with population densities ranging from low to fairly widespread at some sites (MAFBNZ 2010). Based on the delimitation survey findings, it was determined that fully eradicating *Pyura* was not feasible. However, as there was a high level of interest in the local community, it was decided to attempt to reduce or eliminate the species from some high-value sites where population numbers were relatively low. As such, a three stage pilot treatment programme was devised to test whether it is possible to eliminate *Pyura* from isolated areas.

Stage one of the treatment programme was completed in August and September 2010, when a team of local iwi, MPI staff and marine scientists spent several days manually removing *Pyura* populations at two sites; The Bluff (on Ninety Mile Beach) and Whareana Bay. Specific removal techniques are discussed below (Section 3.2.2).

At the same time, a scientific control was established using the population at the entrance to Parengarenga Harbour, where one marked area was cleared and one left alone to compare results (Jones 2010; MPI 2014). The *Pyura* population at The Bluff was determined to be larger than previously believed based on the delimitating survey, extending over an area of approximately 15,000 m^2. Initial results indicated the population at Whareana Bay was completed removed, while approximately 95% of the known population was cleared from The Bluff (Jones 2010).

Stage two of the pilot treatment programme was carried out in late March 2011. The treated sites were revisited to evaluate the effectiveness of the removal efforts and to remove any individuals that had been missed. Following the delimiting survey and Stage one of the pilot treatment programme, *Pyura* was reported from three new locations (see Figure 1). These populations are located at Tokatoka Point (north of Waikuku Beach on the east coast), Rangiputu (near the entrance to Rangaunu Harbour) and at Mitimiti (north of Hokianga Harbour) (Jones 2010). In addition, *Pyura* individuals were noted growing on wharf piles in Houhora Harbour during the Stage two field work (Jones 2011). The results of the treatment at the Parengarenga Harbour site suggest this population increased in density over the six months between treatments, although the total area covered by *Pyura* had not changed and no new individuals were found in the marked areas that were cleared (MPI 2014). Populations at The Bluff and Whareana Bay had also not spread into areas which had been previously cleared (Jones 2011). Although believed to be entirely cleared during Stage one, *Pyura* was still present at the Whareana Bay site, however the density was relatively low (~5-10% coverage; Jones 2011).

Stage three of the pilot treatment programme was carried out in late August 2011. Treatment sites were revisited over a course of three days to remove any *Pyura* found and draw some final conclusions about the removal effectiveness. Significant reductions in population density and coverage were reported at both The Bluff and Whareana Bay sites (Jones *et al.* 2012). In total, 384 hours were spent removing *Pyura* over the three stages including the time needed to carry out monitoring efforts. Conservative estimates from the three sites show a total of 460 kg of *Pyura* was removed over the three stages. A follow-up survey and clearance efforts during June 2012 indicated further reductions in population cover at both sites. At Whareana Bay, the population has declined from 2,445 m^2 (at Stage one) to no visible patches at June 2012. Similarly, at The Bluff, population cover has declined from 15,116 m^2 to only small patches representing 1,236 m^2 (pers. comm. K. Walls, Ministry for Primary Industries). The findings of the pilot programme indicated that manual clearance of *Pyura* is a feasible method for controlling or locally eliminating discrete populations of this sea squirt from high value locations (Jones *et al.* 2012). The monitoring data indicated that densities remained consistent when untouched but, when manual removal is carried out, *Pyura* coverage can be maintained at low levels or possibly eliminated.

3.2. Management techniques available

The proliferation of invasive species and the associated impacts on environmental and economic values has led to an increased demand for tools to mitigate the effects of pest species. Control options generally involve treatments for the reduction or removal of biomass and have had varying levels of success. Management options for minimising the likelihood of human-mediated spread as well as controlling established populations are summarised below.

3.2.1. Measures to minimise human-mediated spread

Domestic pathway management is an important consideration, in particular identifying human-mediated vectors of spread that can potentially transport *Pyura* much further than possible through natural dispersal alone. As discussed above, the recent detection of *Pyura* within at Okiato Point (and its close proximity to Opua marina) has increased the likelihood of regional spread through vessel hull fouling. Management of high-risk vectors, such as recreational vessel movements, may involve:

- the application of anti-fouling paints, in the case of vessel hulls
- increased levels of surveillance, regulation and vessel maintenance to prevent fouling accumulation in 'niche areas' (*e.g.* sea chests) that are often not anti-fouled (Coutts & Dodgshun 2007).

Anti-fouling treatments need to be regular and effective (*i.e.* utilising a toxic paint coating) to minimise further spread of this species via hull fouling. Restrictions on vessel movements if anti-fouling treatments are not up to date may prevent further spread from Opua marina. In response to the detection of the Mediterranean fanworm (*Sabella spallanzanii*) in Whangarei Harbour, a number of marinas in the Northland region are now declining marina berth applications for any vessel that hasn't had anti-fouling paint applied within the past 12 months. Vessels are required to provide information about their recent location, the age of their anti-fouling paint or the date the boat was last removed from the water and cleaned (YNZ 2013).

Activities associated with the aquaculture industry can also lead to the inadvertent transport of fouling species across regional scales. The presence of *Pyura* on oyster farming structures within Parengarenga Harbour and Orongo Bay reinforces the need for management of associated activities. This may include regulations around vessel movements and aquaculture transfers, as well as sterilisation of contaminated aquaculture equipment or seed-stock (*e.g.* Forrest *et al.* 2007). As bivalves are regularly transported among sites for grow-out, routine industry practices regarding the translocation of both stock (*e.g.* mussel declumping and washing) and equipment are currently in place to reduce the risk of spread at regional scales (Wasson *et al.* 2001; Forrest *et al.* 2007). However, as is the case with most fouling control methods, such treatments may not be 100% effective (*e.g.* Forrest & Blakemore 2006).

3.2.2. Measures to control established populations

Localised *Pyura* incursions may be suppressed by the physical removal of first colonisers, particularly if this is done before they have grown to maturity and are able to reproduce. Manual removal of localised *Pyura* populations has been carried out at three sites in Northland. Tools such as paint scrapers, blunt dive knives or flat chisels were used to scrape the *Pyura* off the substrate. Feedback from the initial removal efforts indicated that paint scrapers (specifically 5-in-1® tools) were one of the most effective means of removing *Pyura* from rock substrates and from within crevices. Garden spades were useful for removing numerous individuals off large areas more quickly, in particular areas of flat rock (Jones 2011). More information regarding physical removal of established *Pyura* populations is presented in the MPI field guide (MAFBNZ 2011). As newly-settled individuals are very small and easily missed, it is likely necessary to repeat removal efforts.

Other relatively simple treatments may be suitable under certain circumstances, particularly for populations on artificial structures. The application of physical stressors such as air drying, ultraviolet light, steam, hot water, freshwater immersion, electricity and pressure washing has been used successfully with other high-profile marine pest species (*e.g.* Carver *et al.* 2003; Forrest & Blakemore 2006; LeBlanc *et al.* 2007; Denny 2008; Paetzold & Davidson 2010; Arens *et al.* 2011). In-water plastic encapsulation (‘wrapping’) is an effective treatment method for heavily-fouled vessels and structures. Treatment with relatively eco-friendly chemicals such as bleach and acetic acid is also effective under some scenarios, often at relatively low concentrations (< 5%) (*e.g.* Piola *et al.* 2010). Treatments such as these are likely to be particularly effective for new recruits or small individuals. The use of chemicals generally requires approval from the relevant regional council and the Environment Protection Authority. In a similar manner to plastic encapsulation, smothering techniques using dredge spoil or geotextile fabrics are also an option for control (*e.g.* Coutts 2005; Coutts & Forrest 2007).

Biological control (‘biocontrol’) could also be considered as a treatment method. This would involve artificially increasing the density of native predators (*e.g.* the sea star *Stichaster australis*) to reduce *Pyura* population density. This approach has been applied using kina (sea urchin) during recent eradication attempts for the invasive seaweed *Undaria pinnatifida* in Fiordland (Atalah *et al.* 2013). Sea stars have also been shown to significantly reduce the densities of a range of solitary sea squirts on artificial structures (Atalah *et al.* 2014). Biocontrol could be particularly effective following manual removal efforts. This treatment method is likely to have large non-target effects (*e.g.* reduction in native invertebrate species), the impacts of which would need to be considered. Treatment of infected structures may be particularly important in concentrated aquaculture regions, such as the Marlborough Sounds, where species spread can be facilitated by the large number of artificial structures in close proximity.

3.3. Invasion potential in the Top of the South region

Pyura is able to colonise a range of hard substrates (both natural and artificial) and could become established in a range of locations in the Top of the South region. Habitats within the Marlborough Sounds region are generally sheltered with low wave action, and mainly cobble or boulder substrate on the shorelines. These areas may be less likely to be colonised by *Pyura* as this species shows a propensity for exposed intertidal rocky-reef substrates. The Marlborough Sounds also has an extensive number of artificial structures with surface areas that may be prone to invasion. *Pyura* is unlikely to be limited by any environmental constraints within the region, with temperature and salinity profiles both within this species tolerance.

Based on the species limited larval duration and current distribution at the top of the North Island, *Pyura* is not likely to spread to the Marlborough region through natural dispersal alone. However, the high frequency of vessels visiting the Marlborough Sounds means that spread to this region via human-mediated vectors is a possibility.

3.4. Understanding the costs and benefits of management

Although only present in the far North region, *Pyura* is considered established in New Zealand with MPI regarding the species as 'post-border'. As such, regional councils are responsible for managing any post-border range expansion of *Pyura*, with MPI likely supporting responses but not taking a leading role. Even with complete knowledge of a species' biological characteristics, the outcome of introductions is extremely challenging to predict with any confidence, making it difficult to weigh costs and benefits of management. This is particularly relevant with invasive species that behave differently in different environments as well as through time. However, a robust evaluation is crucial, especially with limited funding available and competing priorities for invasive species management (Molnar *et al.* 2008).

The efficacy of any control or mitigation strategies initiated will depend on the on-going long-term commitment of resources. Eradication or control has been shown to be easier, cheaper and more effective very soon after detection, particularly if the target species is confined to a restricted area (*e.g.* Hopkins *et al.* 2011). The most feasible control method for this species is removal by hand. Although this method is time consuming it has shown promising results at both treated sites in the far North (Jones *et al.* 2012). Recolonisation of cleared areas by *Pyura* appears to be gradual, particularly in areas where the population is isolated from additional sources of recruitment. As such, any sustained and intensive population control efforts for new incursions show a good likelihood of success. As with the pilot treatment programme, surveillance and removal efforts will need to be frequently repeated in the initial stages of any management programme.

4. CONCLUSION

Successful invasive species management in the marine environment is generally reliant on the species having:

- a limited natural dispersal potential
- low fecundity
- specific habitat requirements
- conspicuous morphology and easily visible individuals.

Pyura appears to meet these requirements relatively well. This species pelagic larval duration of ~12 hours means spread through natural dispersal alone is likely to be limited. In addition, the synchronous spawning behavior exhibited and the gregarious nature of sea squirt larvae means retention of propagules close to the parent population is likely. Specific information on fecundity is not available; however, solitary sea squirts are believed to produce large numbers of eggs at each spawning event. This species shows a preference for open environments, particularly exposed rock platforms and rocky-reef habitats. Larvae of *P. stolonifera* in South Africa have been shown to preferentially settle on well-lit and upward-facing substrates (Rius *et al.* 2010). As such, habitats at risk within a region can be identified easily, particularly those close to vessel hubs and sources of human-mediated spread. Lastly, the tendency of this species to form large aggregations of individuals means populations are more likely to be detected than those of small, cryptic species. Difficulties will still arise with regards to detection of newly settled or small individuals however.

A critical information gap that makes management decisions difficult is our understanding of potential impacts to both environmental and economic values. *Pyura* is an aggressive interspecific competitor for primary space and has the potential to considerably alter intertidal community structure and composition. In New Zealand, dense mats of *Pyura* have already engulfed and displaced native green-lipped mussel beds in some areas of the far North (Hayward & Morley 2009). The New Zealand mussel industry is heavily reliant on wild caught spat from this region. As such, research into its impact on mussel reefs in Northland is needed, until which the degree of risk from *Pyura* remains unknown. This species may also become a nuisance fouler on intertidal aquaculture systems such as commercial oyster leases; however, information on competitive interactions between these two species is presently not available. Consideration of a worst-case scenario, *i.e.* significant adverse effects on the regions aquaculture and environmental values, would be prudent when making decisions on whether, and to what extent, to respond to any future *Pyura* incursions.

In addition, reliable information about the reproductive strategies of the *Pyura* populations in New Zealand is lacking. Information on body size at sexual maturity is useful from a management perspective, in order to determine whether individuals may have spawned following detection in a new location. Similarly, an increased understanding of the duration of the reproductive season and critical temperature thresholds for spawning would enable more effective treatment measures for this species. There does not appear to be any current research being carried out on New Zealand *Pyura* populations. This may change with further spread of this species into additional regions and the possibility of negative impacts to key environmental or commercial values.

The results of the far North region pilot treatment programme, suggest it is possible to maintain *Pyura* populations at low densities in semi-isolated locations. The species short larval duration and limited dispersal potential suggest that local elimination may be achievable, especially if more effective clearance techniques are utilised (Jones 2011). Additionally, the intertidal habitat of Pyura populations makes eradication efforts considerably easier and less expensive than those for subtidal species. Specialised contractor services are required for activities such as hand removal by divers, with subtidal management efforts generally requiring significant resources, *e.g.* a recent *Sabella spallanzanii* incursion response in the Coromandel cost the region's council more than NZ$120,000 (Hodges & Simmons 2013). In addition, diver-based responses are logistically more challenging due to affordability of search time, lower detection limits and the requirement for specialised staff.

Consideration should also be given to preventing or slowing the spread of *Pyura* to high-value areas (*e.g.* key aquaculture regions or marine protected areas). A key component of this will be the development of pathway management plans, incorporating strategies such as increased regulations around regular hull anti-fouling in relation to the movement of vessels between regions. The development of pathway management plans between regions is an important component of invasive species management in general, but will require a collaborative approach between neighbouring regions and central government. Although challenging, this may provide the best value for money in the event of multiple incursions or the presence of more than one target species within the region (*e.g. Styela clava*'s recent detection in Picton).

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