Human-mediated pathways of spread for non-indigenous marine species in New Zealand

Timothy J. Dodgshun, Michael D. Taylor and Barrie M. Forrest

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CONTENTS

Appendix 1

Appendix 2

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ABSTRACT

Knowledge of human-mediated transport pathways for non-indigenous marine species (NIMS) to and around New Zealand is important for understanding and managing bioinvasion risks to high-value areas (HVAs). This document describes potential pathways for the spread of NIMS to areas of high conservation value, based on a preliminary list of such localities. This list includes HVAs that are geographically spread throughout New Zealand and vary in size from small discrete areas (e.g. small marine reserves) to expansive regions of coastline (e.g. Fiordland and Stewart Island/Rakiura). Similarly, HVAs range from remote offshore islands to localities close to centres of human activity (e.g. international ports), which may be vulnerable to the natural spread of pest organisms. Vessel traffic and aquaculture activites are highlighted as important pathways for the human-mediated spread of potential pest species. In relation to conservation areas, vessel traffic appears to be of particular significance, with three major mechanisms for the potential transfer of pest organisms: ballast water, hull fouling and sea chests (water-intake recesses in the hull). While ballast water is widely considered as the major present-day mechanism for the global dispersal of NIMS, hull fouling is likely to be particularly important for translocation within New Zealand and may be significant even at local scales. Vessel sea chests can harbour a range of NIMS, including adult life-stages, and are a potential mechanism for the spread of pest organisms directly from infested international source regions to high-value conservation areas around the New Zealand coast. There is a variety of other actual and potential pathways that may be important in the spread of marine pests to and around New Zealand. However, reliable and sufficiently detailed information for many pathways is difficult to obtain, even at a regional scale. This suggests that future effort needs to concentrate on identifying pathways that are of greatest importance in the transfer of NIMS, using a structured, risk-based approach.

Keywords: non-indigenous marine species, marine bioinvasion, pathway, vector, New Zealand

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1. Introduction

Prior to the early part of the 18th century, New Zealand's marine assemblages developed largely in isolation due to the presence of natural trans-oceanic barriers to dispersal. Although a number of mechanisms or life-history adaptations can facilitate natural invasions across oceanic boundaries, such as long-lived planktonic larvae (Scheltema 1971) and rafting (Winston et al. 1996), voyages by ships were probably the most significant factor in removing this barrier. Reports of exotic marine organisms being transported to New Zealand by ships date back to at least 1910, when two apparent vessel-mediated introductions of crustaceans were noted (Chilton 1910). Subsequently, Skerman's (1960) survey of fouling organisms on 89 vessels in New Zealand ports clearly demonstrated the potential for trans-oceanic dispersal on vessel hulls.

Human activities are now considered the primary factor in the spread of non-indigenous marine species (NIMS) around the globe, with a variety of human-mediated dispersal mechanisms being recognised as having greatly accelerated the natural process of invasion (e.g. Carlton 1985, 1989; Cranfield et al. 1998; Hewitt et al. 1999; Leppäkoski et al. 2002; Minchin et al. 2005). By 1998, more than 140 NIMS had been recorded in New Zealand, only four of which were deliberately introduced (Cranfield et al. 1998). Although a number of these introductions (e.g. the Asian kelp *Undaria pinnatifida*, and the sea squirt *Styela clava*) threaten some of New Zealand's highly valued resources, our marine environment still appears to be free of some of the world's most notorious NIMS (e.g. the European green crab *Carcinus maenas*, the northern Pacific seastar *Asterias amurensis*, and the green seaweed *Caulerpa taxifolia*).

Globally, there has been considerable effort to identify risks associated with transport vectors for NIMS (e.g. Carlton 1985; Coutts et al. 2003; Coutts & Taylor 2004; Verling et al. 2005) and to develop management tools for high-risk pathways and associated mechanisms, such as ballast water (e.g. Mountfort et al. 1999; Oemcke et al. 2004). Despite such efforts, effective or affordable management tools are still lacking, with the associated recognition that New Zealand's 'leaky' borders make continued incursions of pest species inevitable (Wotton & Hewitt 2004). Similarly, while post-border management options for NIMS are limited, for an island nation like New Zealand, post-border management, including control of 'internal borders', may be feasible in some cases. For example, Sinner et al. (2000) suggested that even though *U. pinnatifida* was well established in many New Zealand harbours, there remained a number of localities with significant natural values that were not vulnerable to the natural spread of this species and for which management of human-mediated pathways was feasible. Hence, understanding human-mediated invasion pathways for NIMS is important for the development of strategies to reduce the risk of first incursions and for the management of pests that have already become established.

In this document, we provide an overview of human-mediated pathways for the spread of NIMS both to and around New Zealand, based on information gathered from published and unpublished sources, and from telephone interviews with key representatives from the maritime industry and government agencies. This information was collected over 2000–2002 (reported in Dodgshun et al. 2004).

We focus primarily on major pathways associated with vessel movements and inter-regional marine farming activities, as the biosecurity risks from these have previously been recognised (Coutts & Taylor 2004; Hewitt et al. 2004; Floerl & Inglis 2005; Forrest & Blakemore 2006). We also describe a range of other less obvious but potentially important mechanisms. While the primary interest of this work was on pathways directly relevant to areas of high conservation value, for reasons outlined in section 2, much of the pathway information we present has a national focus; we describe pathways or areas of activity in regions that may themselves lack significant conservation values (e.g. ports and aquaculture sites), but which can act as reservoirs for the subsequent spread of pest organisms to localities that do.

2. Defining pathways in relation to high-value areas

The task of reliably characterising human-mediated pathways can be onerous even at regional scales (e.g. Stuart & McClary 2004; Acosta et al. 2006) and a lack of focus for information gathering can mean that considerable effort is directed to obtaining pathway information when only a small portion of it may be relevant for management. Hence, Forrest et al. (2006) proposed a marine biosecurity risk management framework based on the identification of spatially defined high-value areas (HVAs) and the protection of such areas from the adverse effects of pest organisms, building on ideas developed in the management of *U. pinnatifida* (Sinner et al. 2000). While such approaches do not negate the need to consider the efficacy of management actions based around eradication or containment of pest organisms when first detected in New Zealand, the HVA-focused approach is clearly complementary to species-led management, and of particular relevance to the management of pests that spread beyond their initial point of introduction. Importantly, by defining and prioritising HVAs, a focused approach allows clear priorities to be determined in relation to allocation of effort for the collection of pathway information and for subsequent management.

A detailed analysis of pathways in relation to spatially defined HVAs requires an agreed definition of such areas, in a way that also recognises their values relative to each other and sets priorities accordingly. Although conservation-based HVAs were proposed according to specified criteria by Sinner et al. (2000) in relation to the management of *U. pinnatifida*, a list of such HVAs for New Zealand has never been formally developed and nor is there consensus on what areas should be included. As a consequence, an analysis of regional-level pathways for the human-mediated spread of NIMS in New Zealand was not justified in the present study, and was also beyond the scope and budget of the project. Such an analysis should be instigated if and when conservation-based HVAs for New Zealand have been clearly defined and prioritised. Nevertheless, we recognise that it is useful to discuss pathway information with reference to HVAs, since this highlights the critical importance of their definition to all subsequent management decisions. Hence, in this report, we provide a preliminary list of 'example' HVAs (Fig. 1),

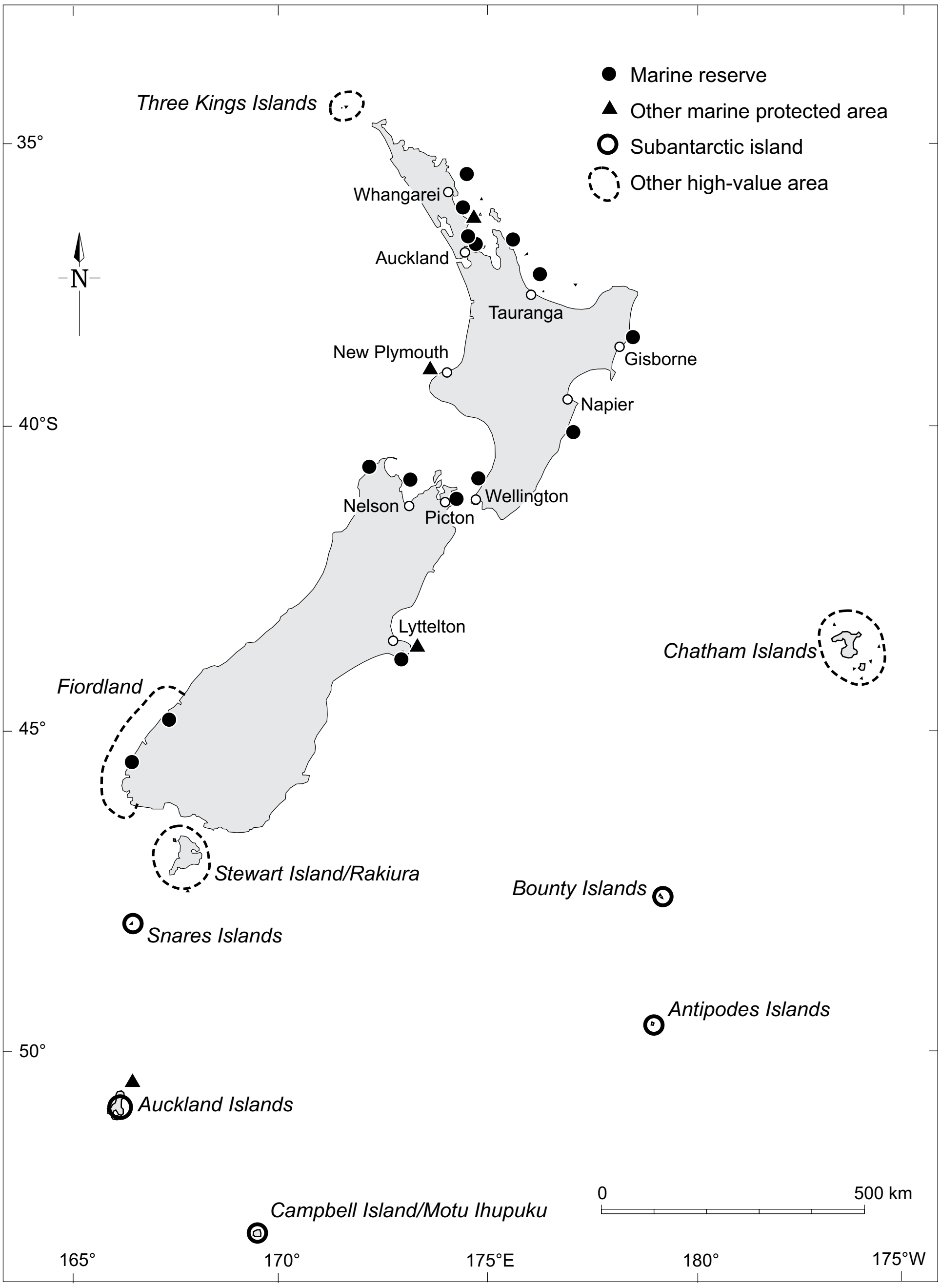

Figure 1. Locations of example high-value areas (HVAs) around New Zealand. Marine protected areas are current as at December 2001.

which were nominally selected according to the criteria outlined in Sinner et al. (2000), namely: areas of high conservation and ecological value, situated mainly in remote locations and exposed to limited vector traffic (e.g. Fiordland National Park, Stewart Island/Rakiura, the subantarctic islands, the Chatham Islands and the Three Kings Islands); representative areas of special value (e.g. Hokianga Harbour); and marine protected areas.

It is assumed that these HVAs have significant conservation values associated with them, although we note that many other geographically defined areas that are not included on Fig. 1 could also be considered to have comparable values. In the Nelson region, for example, only Tonga Island Marine Reserve is shown, but other ecologically important areas include Waimea Inlet (Davidson & Moffat 1990) and the Separation Point bryozoan beds (Bradstock & Gordon 1983). However, for illustrative purposes, the HVAs shown in Fig. 1 are sufficient to demonstrate a number of important features that are central to the management of marine pests and the identification of related pathway information. For example, Fig. 1 shows that HVAs may be geographically spread along the length of New Zealand, suggesting that both generic and site-specific pathway information will be of use in risk assessment, and that a national focus will be required. It is also evident that HVAs could vary in size from small discrete areas (e.g. small marine reserves) to expansive regions of coastline (e.g. Fiordland and Stewart Island/Rakiura), which has implications for the feasibility of management (Forrest et al. 2006). Similarly, HVAs may range from remote offshore islands to localities close to centres of human activity (e.g. international ports). This not only has potential repercussions for management with respect to remoteness and accessibility, but also has implications for invasibility by natural spread from donor areas, based on the premise that HVAs closer to source regions will generally be more vulnerable. A final point is that HVAs may be valued for reasons in addition to conservation; thus, their protection is likely to be in the interests of many stakeholders, which suggests the need for a coordinated approach to marine biosecurity.

3. Human-mediated pathways of spread

Numerous human-mediated pathways for the spread of NIMS have been described (e.g. Elston 1997; Carlton 2001; Nehring 2002), with a summary by Hewitt et al. (2004) identifying at least 20 present-day pathways that could be important in the domestic translocation of NIMS from their initial points of incursion in New Zealand. In the past, one of the more obvious mechanisms for the dispersal of exotic marine species was deliberate introduction. An example is that of the saltmarsh cordgrass *Spartina*, three species of which were deliberately introduced to New Zealand to enhance the sedimentation and 'reclamation' of estuarine tidal flats. (Partridge 1987; Hayward 1997). Subsequent concerns regarding the impacts of *Spartina* led to herbicidal control programmes in many regions (e.g. Gillespie et al. 1990). Various other deliberate introductions of marine species were attempted in New Zealand early in the 20th century. These included European lobsters (*Gammarus vulgaris*), Australian prawns (*Penaeus canaliculatus*), herrings (*Clupea harengus*), turbot (*Psetta maxima*), edible crabs (*Cancer pagurus*), quinnat salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus tshawytscha*) and Atlantic salmon (*Salmo salar*). Of these, only the latter three introductions were successful and only Sockeye salmon gave rise to a self-sustaining anadromous population, the other two becoming land-locked (Hine 1995).

More recently, the significance of vessel movements, marine farming activities and the aquarium trade in the accidental transfer of NIMS has been widely recognised (e.g. Cohen & Carlton 1995; Leppäkoski et al. 2002). The main transport mechanisms associated with local and international vessel movements are ballast water, hull fouling and sea chests (water-intake recesses in the hull; see section 3.3), with hull fouling being a particularly important pathway at regional scales due to its relevance to vessels of all sizes (Coutts & Taylor 2004; Floerl et al. 2004; Floerl & Inglis 2005). Transfers of equipment and shellfish seed-stock between New Zealand localities are the main marine farming activities that may result in the domestic transfer of marine pests, especially bio-fouling organisms (Forrest & Blakemore 2006). In this document, we focus on vessels and marine farming as key pathways, but briefly describe other mechanisms that may be of relevance in certain situations, primarily to highlight the complexity of human-mediated introductions and to recognise the role of uncommon or unusual events.

3.1 BALLAST WATER

3.1.1 Background

Ballast water has been in extensive use since the 1890s (Carlton 1985) and is widely regarded as the main mechanism for present-day global dispersal of marine invaders (e.g. Carlton 1985; Hallegraeff & Bolch 1991; Hay et al. 1997; Hamer et al. 1998; Hewitt et al. 2004). Ballast water is carried in ships primarily to aid stability, to obtain adequate propeller and rudder immersion so that the vessel remains controllable, and to allow sufficient draft forward to prevent severe slamming[1]. Since ballast water is expensive to carry, on any given voyage vessels carry only enough to ensure that these requirements are met; full capacity is likely to be used only in severe weather. Ballast water is a relatively non-selective dispersal mechanism: it can potentially carry almost any species present in a donor environment[2] at the time of ballasting, and may also provide a means for the continued introduction of larval stages of species that have historically been dispersed as juveniles or adults in fouling communities (Carlton 1985). Thresher et al. (1999) suggested that c. 20% of NIMS present in Port Phillip Bay, Australia, had arrived in ballast water, and Cranfield et al. (1998) estimated that 3% of the NIMS in New Zealand probably arrived in ballast water, but that a further 21% may have arrived by either hull fouling or ballast water.

3.1.2 Ballast water discharge in New Zealand

Hay et al. (1997) estimated that international vessels discharged 4–6 million tonnes of ballast water in New Zealand waters each year. While these figures are a rough estimate (derived from vessel tonnage, ship types, cargo volumes and ballast:load ratios), they highlight the potential importance of this mechanism. The Ministry of Fisheries (MFish) marine biosecurity group (now part of Biosecurity New Zealand) and the Cawthron Institute have developed a comprehensive ballast water reporting form and associated database, for the recording and analysis of the ballasting operations of international cargo vessels. This is being extended via the development of a GIS-based tool 'Shipping Explorer' (Taylor 2002), which aims to provide information on high-risk ballast water pathways and high-risk periods for target species (see section 4). Ideally, this database would also be

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[1] Slamming: when the bow of a ship leaves the water and plunges back in again due to severe pitching.

[2] Donor environment: any area, e.g. a harbour or embayment, from which ballast water is uplifted by a vessel prior to a voyage to another locality.

extended to the national level and include pathways in addition to ballast water. Vessels operating exclusively between New Zealand domestic ports are not required to report their ballast water discharge. Thus, at present it is not possible to adequately characterise the ballast-related risk from such vessels. However, some general comments can be made based on the main shipping routes for international and domestic vessels, as shown in Figs 2 and 3, respectively.

Generally, most ballast water is discharged from a vessel over a period that may begin up to 8 hours before initial loading of cargo at the first port of call; discharge continues throughout the operation. This is particularly the case with bulk carriers and it is in the first port (or en route to it) that the introduction of NIMS via ballast water is most likely. However, not all vessels follow this pattern of ballast discharge and some, particularly container ships, can be subject to cargo loading alterations during a voyage, and thus may uplift or discharge ballast in more than one port after their arrival in New Zealand waters. For example, analyses of the MFish ballast water database indicates that 860 international container vessels visited New Zealand ports between January 1999 and January 2000, of which 109 discharged ballast water (some 25 800 tonnes).

Figure 2. Major routes of international vessels to and around New Zealand in 2002.

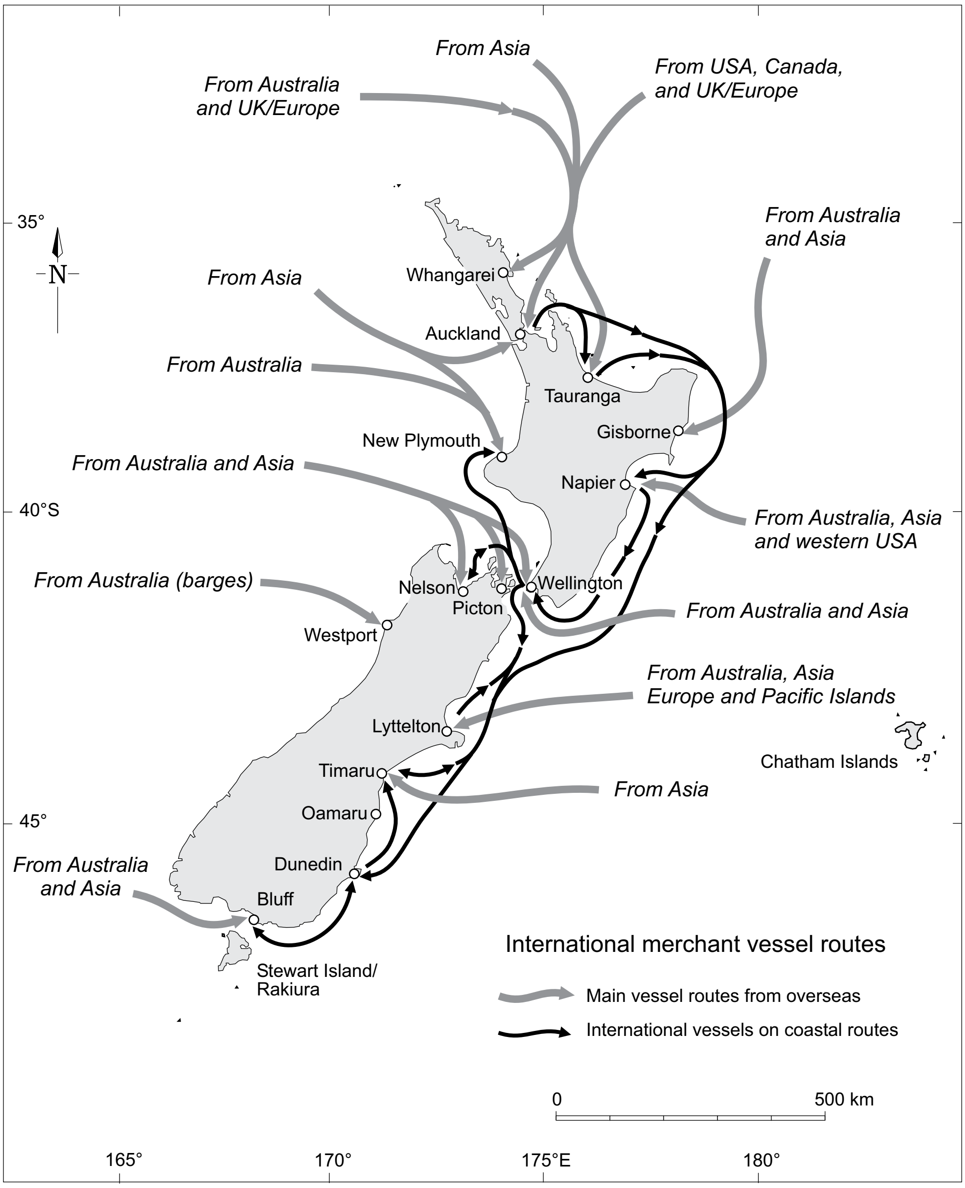
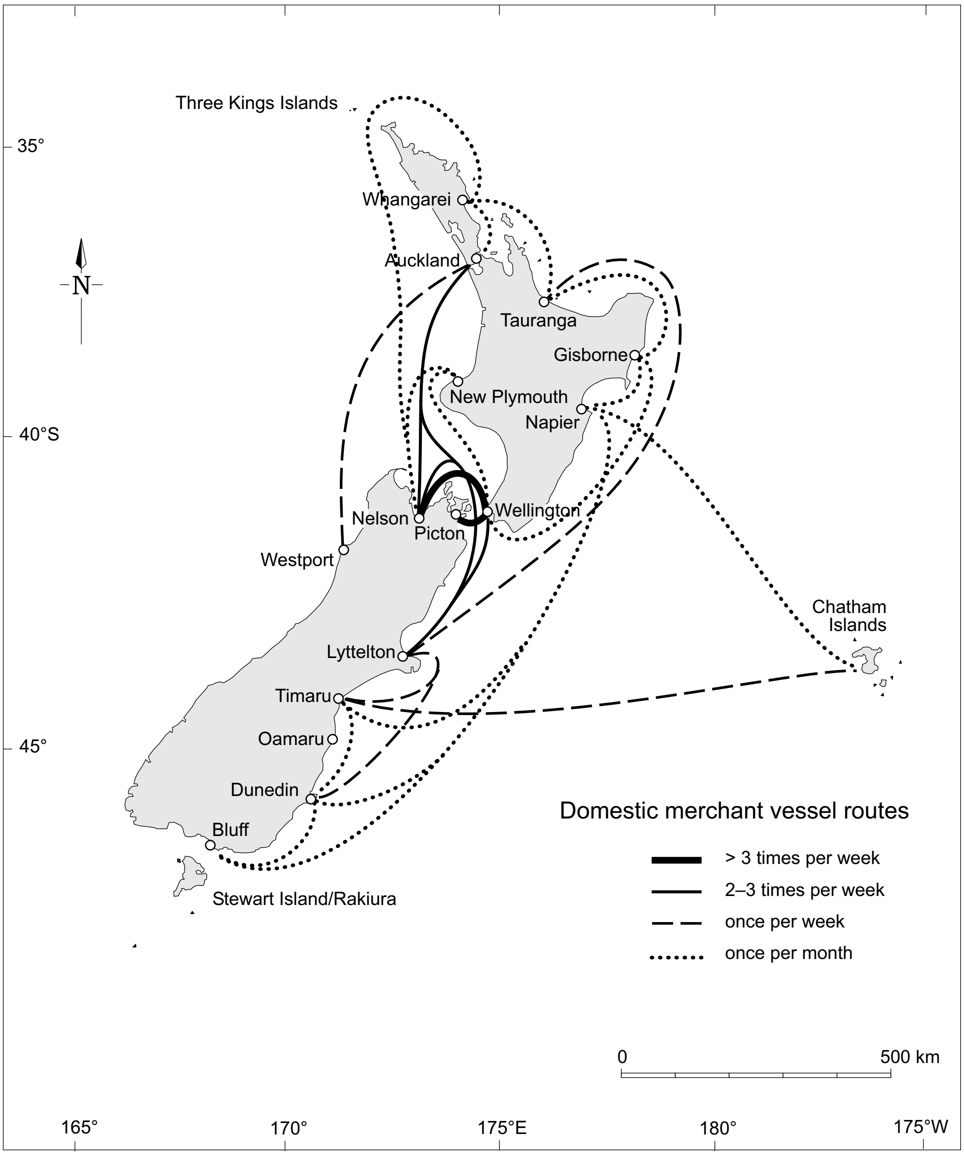


Figure 3. Major routes of New Zealand domestic shipping in 2002.



Although such vessels may not individually discharge large quantities of ballast into New Zealand ports, most are on a regular schedule to the New Zealand coast (Fig. 2); consequently, the frequency of their visits makes them potential inter-port distributors of ballast water organisms. It should be noted, however, that the risk of inter-port transport of such organisms (both new NIMS or those already existing in New Zealand) is not simply a function of the frequency of vessel movements. For example, although analysis of the MFish database shows that Auckland is the busiest port in New Zealand in terms of the frequency of vessel traffic, New Plymouth receives a greater annual discharge of ballast water (Wotton 2001). The significant difference between the two ports is that the majority of vessels visiting Auckland are fully laden container ships that would discharge little, if any, ballast water on arrival, while most of the vessels calling at New Plymouth are bulk carriers and tankers, many of which arrive laden with ballast water that is discharged prior to the loading of petroleum-based products.

Ballast water discharge to ports in close proximity to HVAs may be of particular significance, especially where the HVA is within the natural dispersal range of target species. For example, one would expect the Sugar Loaf Islands Marine Protected Area to be at particularly high risk for certain species, as it is very near the port of New Plymouth. Even where HVAs are not close to ports, it is likely that foreign or locally loaded ballast will be discharged along shipping routes that pass close to them. Examples include the routes taken by log ships that steam the length of Queen Charlotte Sound on their way to Shakespeare Bay near Picton (passing the Long Island-Kokomohua Marine Reserve on the way), and the shipping lanes in the vicinity of the Poor Knights Islands Marine Reserve (see Fig. 2). Understanding such risks requires better information than is currently available on all the shipping routes that pass near HVAs, as well as on the specific ballast water operations (e.g. deballasting locations) carried out by the vessels that travel these routes.

3.1.3 Ballast water exchange

New Zealand currently has an import health standard (IHS) for ballast water that has been loaded within the territorial waters of another country and is intended for discharge in New Zealand waters (BNZ 2005b). With the exception of emergency discharge, the IHS requires that all such ballast water be exchanged in mid-ocean en route to New Zealand. Ballast water exchange is currently recognised by the International Maritime Organisation (IMO) of the United Nations as the only practical and widely applicable way of reducing the spread of NIMS via ballast water discharge, even though it is not entirely effective (Murphy et al. 2004). Indeed, ballast water exchange may, in some circumstances, increase the risk of introducing unwanted marine species, either because of the possible uptake of live organisms during the exchange, or an improvement in water quality resulting in increased reproduction rates of species already present in the tank (Taylor & Bruce 1999).

Recent research has evaluated approaches for identifying suitable areas for mid-ocean ballast water exchange and for ballast discharge in New Zealand waters (Gibbs et al. 2000, 2006). However, there is currently no requirement for ballast water exchange by New Zealand coastal vessels and the exchange times often exceed voyage times between local ports, which would reduce the effectiveness of the procedure (Taylor et al. 1999). Consequently, the risk of spreading NIMS around the New Zealand coast via ballast discharge is currently unmanaged. There is considerable ongoing research into the development of ballast water treatment technologies, along with a current IMO initiative to develop internationally accepted ballast water treatment standards (e.g. Mountfort et al. 1999; Oemcke et al. 2004). Further progress in these areas, including development of treatment technologies that can be applied between New Zealand ports, should eventually result in a reduction in the risks to HVAs from the ballast water pathway.

3.2 HULL FOULING

3.2.1 Background

All sea-going vessels that stay in the water during their normal operations will carry hull fouling organisms. Cranfield et al. (1998) estimated that 69% of the NIMS that have been inadvertently introduced into New Zealand probably arrived on vessel hulls. Hull fouling communities can range from a fine layer of microscopic algae to a mass of encrusting organisms (e.g. bryozoans, barnacles and molluscs), which, in extreme cases, can be regarded as mobile ecosystems (e.g. Carlton 1985; Hay & Dodgshun 1997).

In an extensive *in situ* study of fouling on the hulls of merchant vessels over 10 000 gross registered tonnes (GRT) that was carried out in Tasmania, Coutts (1999) recorded 65 different taxa, including four species that were considered foreign to Tasmanian waters. However, the majority of fast, well-maintained, ocean-going cargo ships seldom have excessive growth on their hulls, as they are generally dry docked, repainted and anti-fouled every 3–5 years during survey (A. Coutts, Cawthron Institute, pers. comm.). An interesting exception was the inter-island ferry 'Arahunga', which was dry docked in Brisbane in early 1999 and found to be carrying approximately 8.5 tonnes of mussels, barnacles and other organisms, presumably of New Zealand origin (Nelson Mail, 14 April 1999). At that time, the vessel was being dry docked biennially rather than annually as it had been previously, illustrating the relative ease with which a simple change in a vessel's maintenance schedule may result in the development of a potential pathway for the spread of marine pests.

In a recent hull fouling study of 30 merchant vessels in New Zealand, Coutts & Taylor (2004) concluded that certain areas of the hulls were more susceptible to fouling than others. These included regions of the hull that lacked antifouling coatings, hydrodynamically protected areas, the inside of dry docking support strips (on which the vessels lie while in dry dock), sea chests (see section 3.3) and rope guards. Similarly, a preliminary study by James & Hayden (2000), which included a sample of 12 cargo vessels examined *in situ* in Wellington Harbour, described the hull fouling encountered as comparatively light (< 7% of the available surface), with heavier fouling in protected areas of the hull.

Certain vessels and structures are especially prone to fouling because of the activities they are involved in. Examples include cargo barges, survey ships, cable- or pipe-laying vessels, cruise ships, and Floating Production Storage and Offloading vessels (FPSOs), each of which may remain inactive in ports or at anchor for long periods. If they suffer damage to (or failure of) their anti-fouling coatings or are poorly maintained, they become particularly prone to fouling. In addition, vessels and structures that are towed to new locations (e.g. barges, drilling platforms, floating docks and FPSOs) travel at low speeds that are likely to favour the survival of many fouling organisms (Foster & Willan 1979; De Felice 1999; Coutts 2002).

Smaller local craft (e.g. fishing vessels and pleasure boats) also constitute a significant risk in the local transport of hull fouling organisms. For example, Hay (1990) implicated fishing vessels in the transfer of *U. pinnatifida* from Wellington to several South Island ports, and a report from the Department of Conservation's (DOC's) *U. pinnatifida* eradication project has confirmed that fishing vessels are a likely pathway for the relocation of this seaweed (Cooper 2001). The data compiled for this control programme were derived from surveys of a cumulative total of 941 vessels (mainly fishing craft, yachts and launches) between Timaru and Stewart Island/Rakiura, 331 of which were or had been fouled with *U. pinnatifida*.

Major hull fouling pathways for the transport of NIMS around the New Zealand coast are described in more detail below. The key pathways considered are:

- International and domestic shipping services
- Tourist and cruise vessels, particularly those travelling to the subantarctic islands and Fiordland
- Fishing vessels
- Moored recreational vessels
- Barges

Other studies are underway or completed that will provide further detail on some of these pathways or for specific regions (e.g. Stuart & McClary 2004; Acosta et al. 2006), including a national study of hull fouling risks funded by Biosecurity New Zealand.

3.2.2 International and domestic shipping services

The transport routes of international and domestic ships, which are summarised in Figs 2 and 3, also apply to the transport of hull fouling organisms. However, as noted in the previous section, these vessels (which include both cargo and passenger ships) are usually well-maintained and so are unlikely to be heavily fouled. Further, since these vessels travel from port to port, the risk of direct hull fouling transfers to conservation-based HVAs will be relatively low in most cases, although there are some important exceptions. For example, Fig. 3 indicates vessel routes to the Chatham Islands, consisting of one monthly visit from Napier and a weekly visit from Timaru. There are also direct routes to the Kermadec Islands taken once or twice a year by both the Royal New Zealand Navy and charter vessels. HVAs in close proximity to ports may, in some cases, also be subject to a relatively greater risk from fouled hulls, as discussed with respect to ballast water (section 3.1.2).

3.2.3 Tourist and cruise vessels

Tourist and cruise vessels operate New Zealand-wide. Since these vessels regularly visit relatively pristine areas on remote coasts or adjacent to national parks and similar conservation areas, they have the potential to transport non-indigenous fouling organisms directly to HVAs (see Fig. 4 and Appendix 1). In this respect, tourist and cruise vessel operations differ from those of most other large vessels that visit New Zealand and their biosecurity risk to New Zealand has been recognised in a report by the Parliamentary Commissioner for the Environment (Burrowes et al. 2003).

While tourist and cruise vessels may uplift ballast water in order to replace lost weight due to fuel consumption, it is unlikely that they would discharge it during routine voyages. This is because, apart from mandatory ballast exchanges on the high seas, cruise ships only de-ballast in ports when they take on fuel, or during extended port visits, when small quantities may be discharged to allow

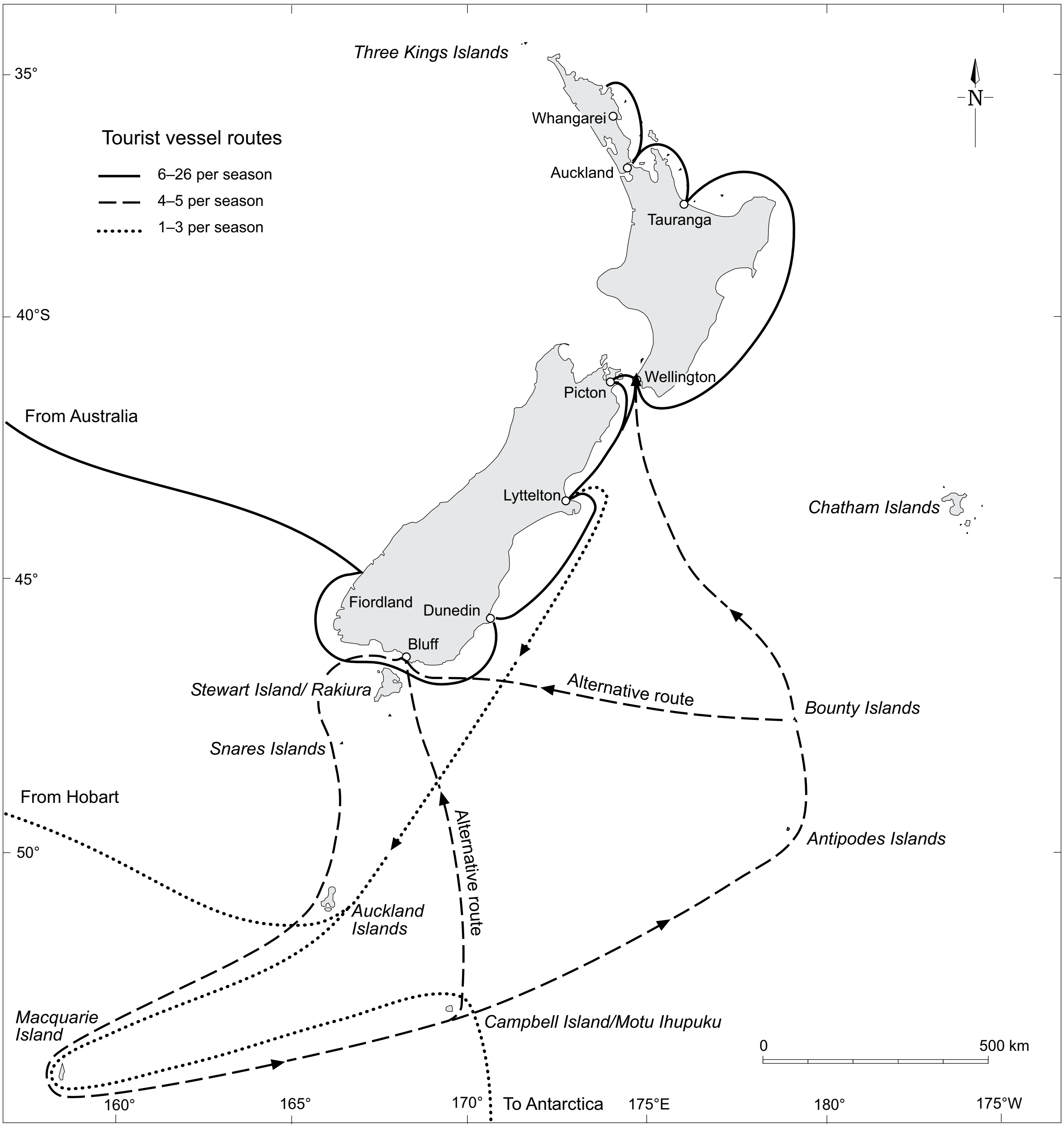


Figure 4. Major tourist vessel routes in the vicinity of Fiordland and the subantarctic islands 2001–2002.

for disposal of waste-water. Although the frequency, volume and location of ballast discharge will vary with vessel size and type, and vessel voyage duration and pathway, our calculations indicate that discharge volumes will be minimal even in the worst case. Hence, it is reasonable to assume that hull fouling and sea chests are likely to be more significant than ballast water as transport mechanisms for NIMS via tourist and cruise vessels.

The identification of all the relevant tourist and cruise vessels throughout New Zealand, as well as their areas of activity, is not justified without the prior development of a definitive list of HVAs. Therefore, in this report we focus on the subantarctic islands and Fiordland as two areas of exceptionally high conservation value, where remoteness makes NIMS surveillance and incursion response extremely difficult (and thus vector management particularly important). These two examples are also interesting because the tourist and cruise ships used for long voyages to such remote locations are mainly large vessels. Although these vessels are not particularly vulnerable to hull fouling (since they generally enter dry dock for survey every 2 years), they have large sea chests (see section 3.3) compared with other vessels, reflecting the large seawater intake volumes required for their desalination plants.

Subantarctic islands

There has been a gradual increase in the number of visits by tourist vessels to New Zealand's subantarctic islands over the summer season (November–February), from 9 in 1995–1996 to 12 in 1999–2000 (Southland Conservancy, DOC, unpubl. data) (Fig. 4). Over the last 5 years, a total of 48 visits to the islands by tourist craft have been recorded, with vessels spending 1–2 days at each island over the summer months (DOC 1999). The majority of these vessels sailed from three ports: 25 from Bluff, 8 from Hobart (Tasmania) and 4 from Lyttelton. Of the remainder, two vessels sailed from Ushuaia (Argentina), and one each from Auckland, Wellington, Akaroa, Dunedin, Stanley (Falkland Islands) and Albany (Australia).

The two largest visiting vessels were icebreakers: a vessel of 12 228 gross registered tons (GRT), and a smaller ship of 2140 GRT. The former visits the subantarctic islands between three and five times per season, while the latter calls at the Auckland, MacQuarie and Campbell Island groups about twice per season on voyages between Hobart and Antarctica. Hobart is known to have a number of potential high-risk marine species, including the northern Pacific seastar *Asterias amurensis*; hence, direct shipping routes from Hobart to these islands are significant. Although DOC permits are required to land on any of the subantarctic islands, DOC has no jurisdiction over vessels sailing in their vicinity or anchoring nearby. Vessels are most at risk of introducing NIMS to the subantarctic islands when at anchor or lying close to an island for any appreciable length of time. Occasions when this could occur might include during bad weather or when allowing tourists a closer viewing of an area.

Fiordland

Examination of cruise ship schedules presented on the websites of the Port of Otago and the Lyttelton Port Company[3] indicates that between December 2001 and May 2002 ten passenger vessels visited Fiordland on 27 occasions (K. Swinney, Environment Southland, pers. comm.) (Appendix 1). Approximately half of these vessels visited Hobart, Tasmania, before their arrival in Fiordland, thus representing a high-risk pathway for reasons described above. The ships ranged in size from the *Clipper Odyssey*, which was 102.9 m length overall (LOA) and 5218 GRT, to the *Queen Elizabeth 2*, which was 293.5 m LOA and 70 327 GRT. Larger vessels have visited since then. The large vessels spend a limited time (usually up to 12 hours) cruising in and between the southern fiords. However, one or two of the smaller ships (i.e. those of c. 5000 GRT) may stay 3–4 days.

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[3] Websites: Port of Otago (www.portotago.co.nz); Lyttelton Port Company (www.lpc.co.nz).

Environment Southland has developed a deed of agreement with the New Zealand cruise ship industry that aims to minimise any adverse effects (including the introduction of marine pests) from cruise ships entering coastal waters under its jurisdiction, which includes the waters of Fiordland (Environment Southland 2001). Among other obligations in connection with discharges to air and water as well as navigational and safety issues, schedule four of the agreement requires that ships' owners/operators, masters, crew and pilots observe a prohibition on hull cleaning, painting or scraping (S4.2.3) and ballasting or deballasting (S4.2.15) while the vessels are in internal waters[4]. Note that after visiting Fiordland, two or three of the smaller vessels call at Stewart Island/Rakiura or sail directly back to Australia. However, the first port of call for most of the vessels listed in Appendix 1 is Port Chalmers near Dunedin, where they stay for an average of c. 10 hours. Therefore, Port Chalmers is a logical focal point for monitoring visiting overseas cruise ships, as it is liable to be the first recipient port in New Zealand for any high-risk NIMS that these vessels may be carrying.

3.2.4 Commercial fishing vessels

Data on the localities at which fishing vessels are registered in New Zealand are summarised on Fig. 5 and given in Appendix 2. Unlike the pathways of merchant and tourist vessels described above and shown in Figs 2–4, the movements of fishing vessels around New Zealand, or even in the vicinity of specific HVAs, cannot be easily determined. This is mainly because fishing vessels do not always follow defined schedules or routes.

There are approximately 1626 registered vessels involved in the New Zealand marine fishing industry (Appendix 2). Of these, 71 are large New Zealand-flagged vessels that form part of a deep-sea fleet of 111 ships (the balance of which are foreign-flagged). All have an LOA > 28 m, and all land their catch in New Zealand ports (Mike Lindsay, MFish, Wellington, pers. comm.). Of the 40 foreign-flagged vessels in this fleet, 22 have fished out of New Zealand ports continuously in recent years, with three others occasionally landing their catch in New Zealand. There are also two separate groups of five Japanese boats that fish New Zealand waters seasonally (one group in winter, the other in summer) and then return to Japan (Rebecca Perrot, FishServe, Wellington, pers. comm.).

Prior to and during the catching seasons for various species (e.g. tuna *Thunnus* spp., hoki *Macruronus novaezelandae*, squid *Nototodarus* spp., southern blue whiting *Meromesistius australis*, and orange roughy *Hoplostethus atlanticus*), the larger fishing vessels unload their catch in certain ports in order to be close to the fishing grounds (Table 1). All large fishing vessels (i.e. LOA > 28 m, as mentioned above), both domestic and chartered, are required by New Zealand fisheries legislation to carry an Automatic Identification System (AIS), which enables their movements and positions to be transmitted to MFish (M. Lindsay, MFish, Wellington, pers. comm.). However, aside from these craft, available registration figures do not differentiate between smaller fishing vessels that require permanent berths and the multitude of small craft (the 'mosquito fleet') that are launched from trailers (e.g. used in fishing for paua, *Haliotis iris*).

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[4] Internal waters: the internal waters of Fiordland and Stewart Island/Rakiura as identified on maps appended to the agreement.

Figure 5. Distribution of registered fishing vessels in New Zealand in 2002.

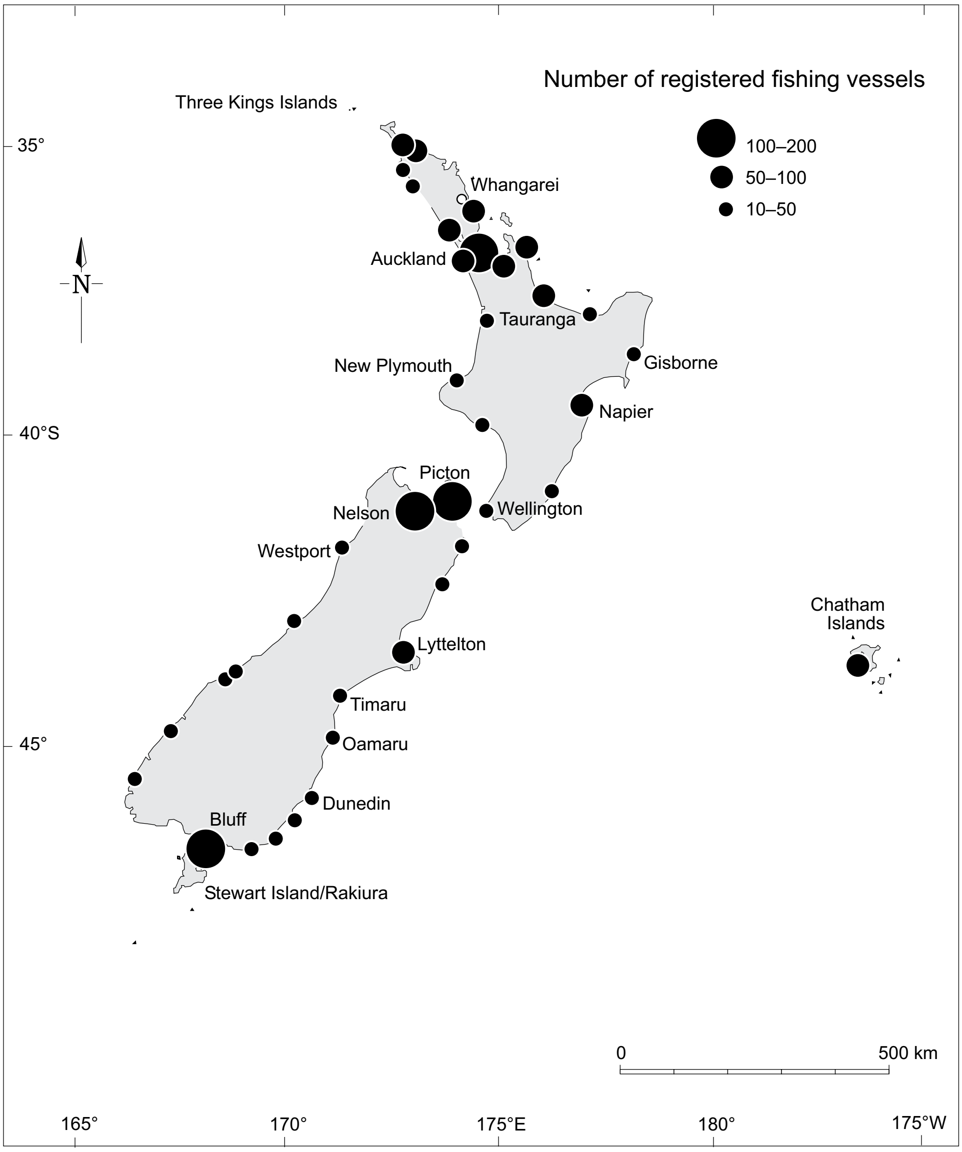


TABLE 1. APPROXIMATE NUMBERS OF FISHING VESSELS VISITING NEW ZEALAND PORTS BY FISHING SEASON (R. BROWN, MASTER OF A DEEP SEA FISHING VESSEL (MDSFV), NELSON, PERS. COMM.).

SPECIES	SEASON	APPROX. NO. VESSELS	PORTS UNLOADED
Hoki (*Macruronus novaezelandae*)[a]	Late July–September	50[b]	Nelson, Wellington, Picton
Southern blue whiting (*Meromesistius australis*)[a]	September–early October	50[b]	Nelson, Lyttelton, Dunedin
Orange roughy (*Hoplostethus atlanticus*)	Year round	5 (foreign)	Wellington, Greymouth, Nelson, Dunedin
Tuna (*Thunnus* spp.)	December–April	100	Tauranga, Onehunga, New Plymouth, Greymouth
Squid (*Notodarus* spp.)	October	50[b]	Nelson, Lyttelton, Dunedin
Scampi (*Metanephrops challengeri*)	Year round	6–7	Auckland, Timaru, Dunedin, Bluff

[a] The same group of vessels are re-deployed to other fish resources as the season progresses.

[b] Fished for by both local and foreign vessels.

In addition, the operators of these smaller vessels are currently not required to notify any authority regarding the dates, intended destination or duration of their voyages prior to sailing. Retrospective data could perhaps be obtained from licensed operators using catch returns filed under the New Zealand Fisheries Regulations 2001, but the information would be approximate and access to it restricted because of its confidential nature. Consequently, the number of fishing vessels operating around New Zealand at any particular time and place is very difficult to ascertain, especially in the North Island where most of the 'mosquito fleet' is located.

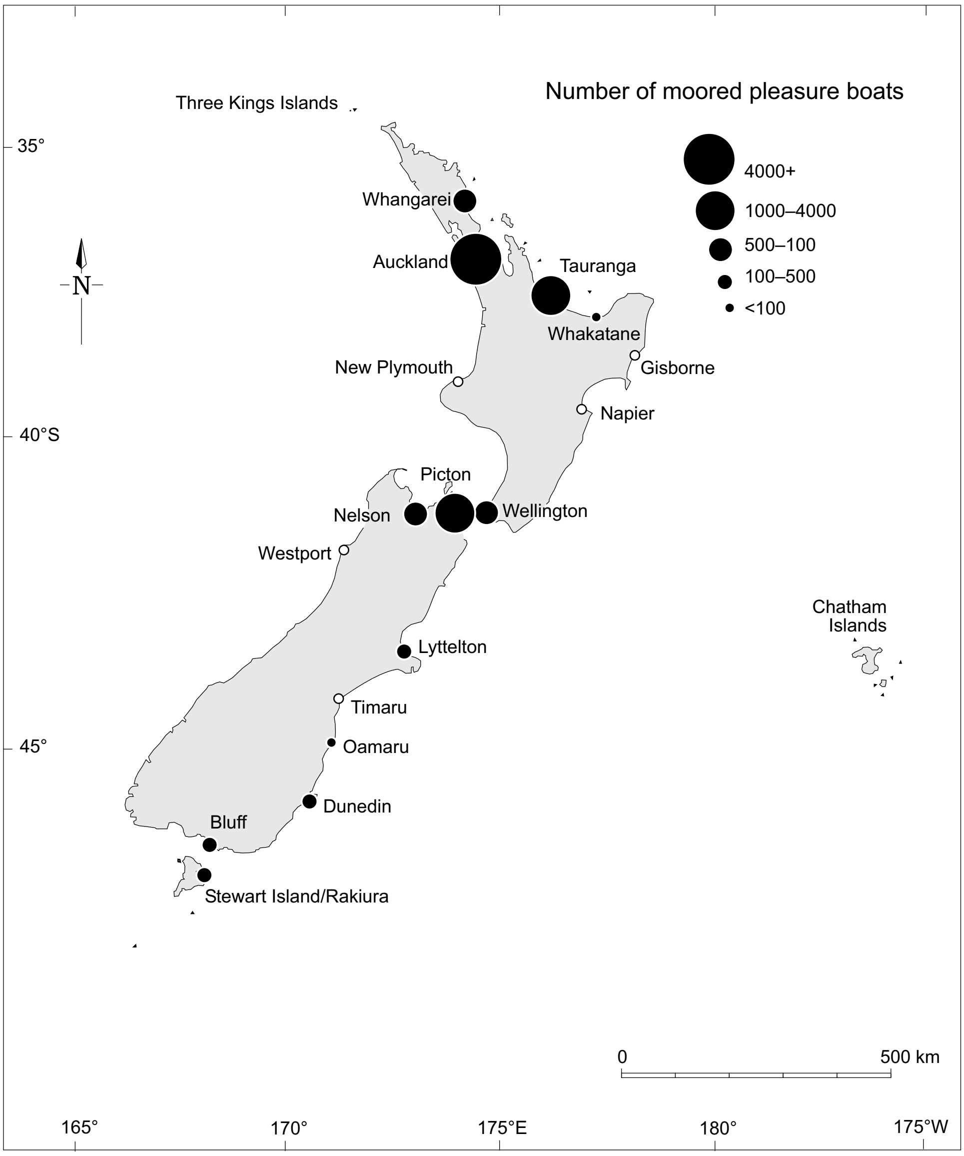
The scampi (*Metanephrops challengeri*) fishery provides an example of the unpredictable nature of fishing vessel movements, especially with respect to HVAs. The areas around New Zealand where scampi concentrations are known are not strictly delineated and vary from season to season. As a consequence, vessel operational areas vary within and between years: for example, they may work for a period of time in areas off the east coast of the South Island, but may then travel as far south as the subantarctic islands (M. Lindsay, MFish, Wellington, pers. comm.). Depending on the whereabouts of the scampi, the trawlers may operate from Auckland, Timaru, Dunedin or Bluff. In recent years, a fleet of six or seven trawlers has regularly fished for scampi in the vicinity of the subantarctic islands. The timing of this activity is unpredictable; however, the vessels usually spend c. 30 days on each trip, of which c. 10 days may be spent sheltering in Carnley Harbour, Port Ross or Waterfall Inlet on the Auckland Islands (M. Stuart, Southland Conservancy, DOC, pers. comm.). This makes the subantarctic islands vulnerable to NIMS that have the potential to colonise these areas.

The biosecurity risk from commercial fishing vessels will also depend on the nature and extent of fouling. With the exception of trailer-borne craft (see section 3.5), the hulls of locally owned fishing vessels are generally cleaned annually and most foreign-owned vessels are cleaned every 3–5 years (R. Busch, Nicholson Marine Coatings Ltd, Nelson, pers. comm.). The New Zealand Fishing Industry Association (NZFIA) has adopted a voluntary code of practice for the chartering of foreign-owned or sourced fishing vessels, to reduce the risk of heavily fouled craft entering New Zealand waters (NZFIA 1997). This was in response to the case of the F/V *Yefim Gorbenko*, a Russian trawler found to be heavily fouled when dry docked at Devonport in 1995 (Hay & Dodgshun 1997). While yearly hull cleaning and anti-fouling of vessels is likely to result in some risk reduction (Coutts & Taylor 2004; Floerl & Inglis 2005), in certain circumstances (e.g. where a fast-growing species or a microscopic fouling stage is present) it may be insufficient to prevent the spread of marine pests to HVAs. For example, DOC's *U. pinnatifida* monitoring programme indicates that fishing boats can be pathways for the seaweed despite current hull cleaning and anti-fouling practices (Southland Conservancy, DOC, unpubl. data). Hence, for *U. pinnatifida* and probably other NIMS, regular (more than yearly) maintenance and rigorous inspection of hulls prior to departure for HVAs may be a necessary risk management action.

3.2.5 Moored recreational vessels

As is the case for many small commercial fishing vessels, a general response from recreational fishers, other boaties and people involved in managing marinas indicated that the movements of recreational vessels around the New Zealand coastline are frequent and largely unpredictable. New Zealand's fleet of recreational boats, including moored (e.g. large yachts and motor launches) and trailer-borne (e.g. yachts, launches and runabouts) vessels, number over 56 000 (Appendix 2). Information based on figures published by Richardson & Ridge (1999) and enquiries made with marina operators nationwide indicate that there are approximately 32 mooring facilities for pleasure boats in New Zealand. In total, these provide for c. 10 100 vessels. The facilities include marinas, boat harbours and other smaller mooring areas, the majority of which are located in the Auckland and Northland regions (Fig. 6). The largest marina, Westhaven in Auckland, provides berths for 1850 vessels (Ports of Auckland 2000). In addition, there are five proposed marinas due for development, which will increase the New Zealand-wide capacity to c. 11 200 vessels. This estimate of the numbers of swing moorings and marina berths in New Zealand differs substantially from

Figure 6. Distribution of moored recreational vessels in New Zealand in 2002.



that of Busfield (2000), who indicated a total of 22 000 vessels 'either berthed in one of the 12 000 marina berths or 10 000 swing or pile moorings around the country'.

Many pleasure boats often remain in marinas or on swing moorings for months (or in some cases even years) between short periods of use. These conditions lend themselves to the vessels becoming heavily colonised by fouling organisms. The hulls of most moored pleasure boats, in particular yachts, are cleaned each year, but some lie at berth uncleaned for months or even years at a time. Unless these craft are regularly cleaned and their hulls coated with an appropriate anti-fouling compound, they constitute potential pathways for NIMS if they leave their moorings. For example, James & Hayden (2000) reported that fouling on a sample of 26 overseas yachts berthed in Gulf Harbour Marina north of Auckland varied from 23% cover on the hulls to 66% on the keel bottoms. In addition, of 212 yachts and 232 launches examined by DOC from May to September 2000 in ports between Timaru and Bluff, 47% of yachts and 30% of launches were fouled with *U. pinnatifida* (M. Stuart, Southland Conservancy, DOC, pers comm.). Although the nature of vessel survey work means that it is time consuming and expensive, it may be the only practical method for obtaining a clear indication of the importance of these craft as potential transfer mechanisms for marine pests. Currently, if a NIMS was detected on a recreational vessel, the only tool available to compel the owner to clean the vessel's hull would be to use the provisions of the Biosecurity Act 1993, provided that the organism was a species listed as unwanted or was declared so immediately after detection.

3.2.6 Barges

Sea-Tow Ltd, a tug and barge company jointly owned by Northland Port Corporation and Adsteam Marine Ltd, Australia, operates up to four tugs on tramp services[5] around the New Zealand coast. In addition to the tugs, their New Zealand fleet comprises four barges: one of 8000 tonnes, one of 3500 tonnes and two of 1000 tonnes (MacIntyre 2000). A number of companies also operate barges in the Marlborough Sounds, some as service or storage vessels for marine farms, and others for the transport of logs or livestock. As these vessels operate intermittently, often under contract, it is difficult to forecast exactly where they are likely to be working at any particular time. Barges are often left at anchor for long periods between operations, and during these times may be readily colonised by fouling organisms, making them potential pathways for marine pests if they are towed to another locality without first being cleaned. Poorly maintained barges that are operated in a particular locality may, therefore, be capable of transferring fouling organisms directly from a shipping port to any nearby HVA.

An example that highlights the role played by barges in the translocation of marine pests is the case of the *Steel Mariner*. This barge was surveyed by Cawthron Institute in Shakespeare Bay, Picton, in December 2001, and an extreme level of fouling was discovered on the hull. The fouling biomass was dominated by an unidentified ascidian, which was later described as a new species, *Didemnum vexillum*, whose status as native v. non-indigenous is unclear

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[5] Tramp services: irregular trade voyages, scheduled runs or time schedules that are not limited to any particular type of cargo other than by the construction of the vessel.

(Kott 2002; Coutts & Forrest 2007). The species formed colonies up to 3 m long that drooped beneath the hull, with an estimated total biomass of c. 2923 kg, equating to 1–2 kg/m^2 (Coutts 2002). *Didemnum vexillum* is a biofouling threat and the species has since spread to other artificial structures in Shakespeare Bay, including a temporarily moored salmon rearing cage that was then moved to a marine farming region in outer Queen Charlotte Sound (Coutts & Forrest 2007). Managing *D. vexillum* in Shakespeare Bay was initially a relatively inexpensive exercise involving treatment of the barge (Sinner & Coutts 2003); however, now that the species is more widespread in the Marlborough Sounds, managing it would be a more complex and costly task with a greater risk of failure.

3.3 SEA CHESTS

Sea chests are recesses built into a ship's hull that house intake piping via which water is pumped aboard for ballast, engine cooling and fire fighting. They are usually positioned adjacent to the engine space on the bottom of the hull, and vary in number from two to about six, depending on the size of the vessel. Each sea chest is covered with a flush-fitting steel grill with aperture holes c. 15–25 mm diameter, or slots 20–25 mm wide and up to 250 mm long (Fig. 7). These grills serve as primary filters to prevent the uptake of debris and large marine organisms.

Sea chests provide a relatively sheltered environment for free-living and sessile marine organisms, as opposed to the exposed areas of the hull that are subject to the 'slipstream' effect of a vessel's movement through the water. They often contain sediments that have been uplifted when the material is suspended in the water column (e.g. during periods of bad weather) or when a vessel settles close to or onto the sediment layer in a harbour during low tide (A. Coutts, Cawthron Institute, pers. comm.). This makes the sea chests susceptible to colonisation by numerous marine species, as described by Coutts et al. (2003) who, in a preliminary investigation in Tasmania, found over 50 individuals of the introduced European clam *Corbula gibba* and three adults (including ovigerous females) of the introduced European green crab *Carcinus maenas* in the sea chests of a passenger ferry operating between Devonport, Tasmania, and Melbourne, Victoria. Similarly, a range of NIMS were recorded during a survey of large ocean-going fishing vessels and small cargo ships slipped or dry docked in Nelson, Lyttelton and Auckland (Coutts & Dodgshun 2005; Fig. 8).

Transport routes for sea chests will be the same as those described above for international and coastal ships, tourist/cruise ships, and large fishing boats (Figs 2–4), since these are the main vessel types on which sea chests are present. Research is currently underway investigating methods to reduce the incidence of marine organisms associated with sea chests, including a preliminary assessment of the efficacy of cathodic protection systems for controlling marine growth in sea chests of Pacifica's New Zealand coastal vessels (Coutts et al. 2003). Future work in New Zealand will also consider the efficacy of *in situ* steam sterilisation as a treatment method.

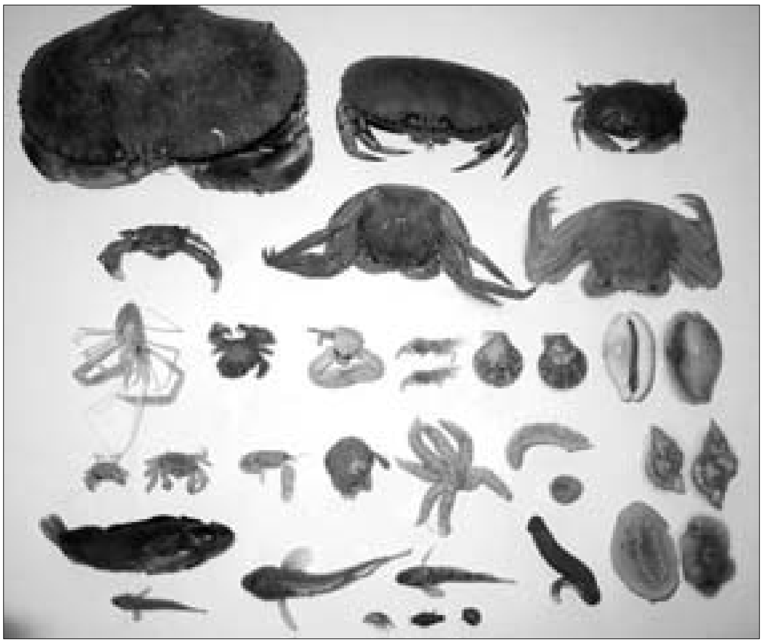

Figure 8. Illustration of the diversity of motile animals found in sea chests of a vessels visiting New Zealand (courtesy of A. Coutts, Cawthron Institute). Included are various species of crab, shrimp, mollusc, starfish and fish.

Figure 7. Seachest intake and grill.

3.4 AQUACULTURE ACTIVITIES: VESSELS, EQUIPMENT AND STOCK MOVEMENTS

3.4.1 Overview of risks associated with aquaculture activities

The deliberate transplantation of aquaculture species is an important international pathway for the inadvertent introduction of NIMS (Elton 1958). Various oyster species, for example, may contain parasites, have heavily fouled shells, or be transported in exotic seaweed packaging, which itself can be heavily colonised (Duggan 1979). Oyster transplants have been implicated in the transfer of a number of notorious invaders, including gut parasites such as *Mytilicola orientalis* (Utting & Spencer 1992) and *Marteila* spp. (Duggan 1979); invasive molluscs such as slipper limpets *Crepidula fornicata*, and Atlantic oyster drills *Urosalpinx cinerea* (Duggan 1979); and invasive seaweeds such as *Sargassum muticum*, *Laminaria japonica* and *U. pinnatifida* (Rueness 1989). In San Francisco Bay, 30 species, representing c. 15% of the introduced biota, are now recognised as having originated from the activities of the Atlantic oyster (*Crassostrea virginica*) industry in the late 19th and early 20th centuries (Cohen & Carlton 1995).

The main products from New Zealand's marine aquaculture industry (in order of decreasing economic importance) are Greenshell™ mussels *Perna canaliculus*, Pacific oysters *Crassostrea gigas*, quinnat (or king) salmon *Oncorrhynchus tshawytscha*, and paua (abalone) *Haliotis iris*. In terms of total area, national coverage and export earnings, long-line mussel farming is by far the most dominant activity. There appear to be no reports of NIMS being introduced to New Zealand as a result of aquaculture activities. However, the tendency of many exotic marine organisms (e.g. *U. pinnatifida* and the Mediterranean fanworm *Sabella spallanzanii*) to colonise floating or suspended structures (e.g. Floc'h et al. 1996; Hewitt et al. 1999; Forrest et al. 2000) means that marine farms are potentially important reservoirs for the secondary spread of NIMS.

Inter-regional activities within the industry can be significant pathways for the spread of associated pest species (Forrest & Blakemore 2006), which exposes the industry to the economic consequences of those transfers (e.g. crop losses caused by the proliferation of fouling pests). Such activities may include the movement of shellfish seed-stock and associated materials (e.g. ropes, frames and seaweed), vessel movements, and post-harvest transfer of shellfish to processing facilities and associated waste disposal. The overview given below of existing and proposed aquaculture areas in New Zealand, and the description of inter-regional transfer pathways for equipment and seed-stock, have been summarised from a report by Forrest & Blakemore (2002).

3.4.2 Description of marine farming areas

Marine farming is concentrated in five main regions and several less intensively farmed areas (Fig. 9). The reliance of the industry on high water quality means that most aquaculture sites are located in relatively unmodified coastal areas, which can put them in conflict with conservation values. An example is in Big Glory Bay, Stewart Island/Rakiura, where intensive marine farming occurs (c. 175 ha of consented water space), and where a programme to eradicate *U. pinnatifida* was in place between 1997 and 2004.

Pacific oysters, and to a lesser extent Greenshell™ mussels, are raised in North Island areas, with intertidal oyster farming primarily occurring in the numerous estuaries and harbours north of Auckland, and mussel farming in the Hauraki Gulf and Firth of Thames area including Coromandel Peninsula, and Waiheke Island and Great Barrier Island (Aotea Island). The other active areas in the North Island are Kawhia and Aotea Harbours on the west coast, with one oyster farm in Kawhia Harbour, one mussel farm used for spat catching in Aotea Harbour. Experimental mussel lines have also recently been developed offshore from Napier in Hawke Bay (Fig. 9).

Mussel farming is by far the most dominant marine farming activity in the South Island, with the most extensive region being the Marlborough Sounds (Fig. 9). This area is characterised by numerous small (typically 3–4 ha) long-line mussel farms, which occupy c. 98% of the total farmed area; the remaining area comprises Pacific oysters or sea-cage salmon farms. While some mussel growing occurs in Golden Bay, most of the consented areas in Golden and Tasman Bays are for mussel and scallop spat catching. A mussel farm is currently operating in Pigeon Bay, on the northern side of Banks Peninsula, and in September 2005 consent was granted for a 2695-ha site in Pegasus Bay near Christchurch (Quality Planning 2005[6]). Big Glory Bay, Stewart Island/Rakiura, forms the most southerly region of intensive marine farming. The majority of the 175 ha occupied by farms

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[6] The Quality Planning Project is a partnership between the New Zealand Planning Institute, the Resource Management Law Association, Local Government New Zealand, the NZ Institute of Surveyors and the Ministry for the Environment.

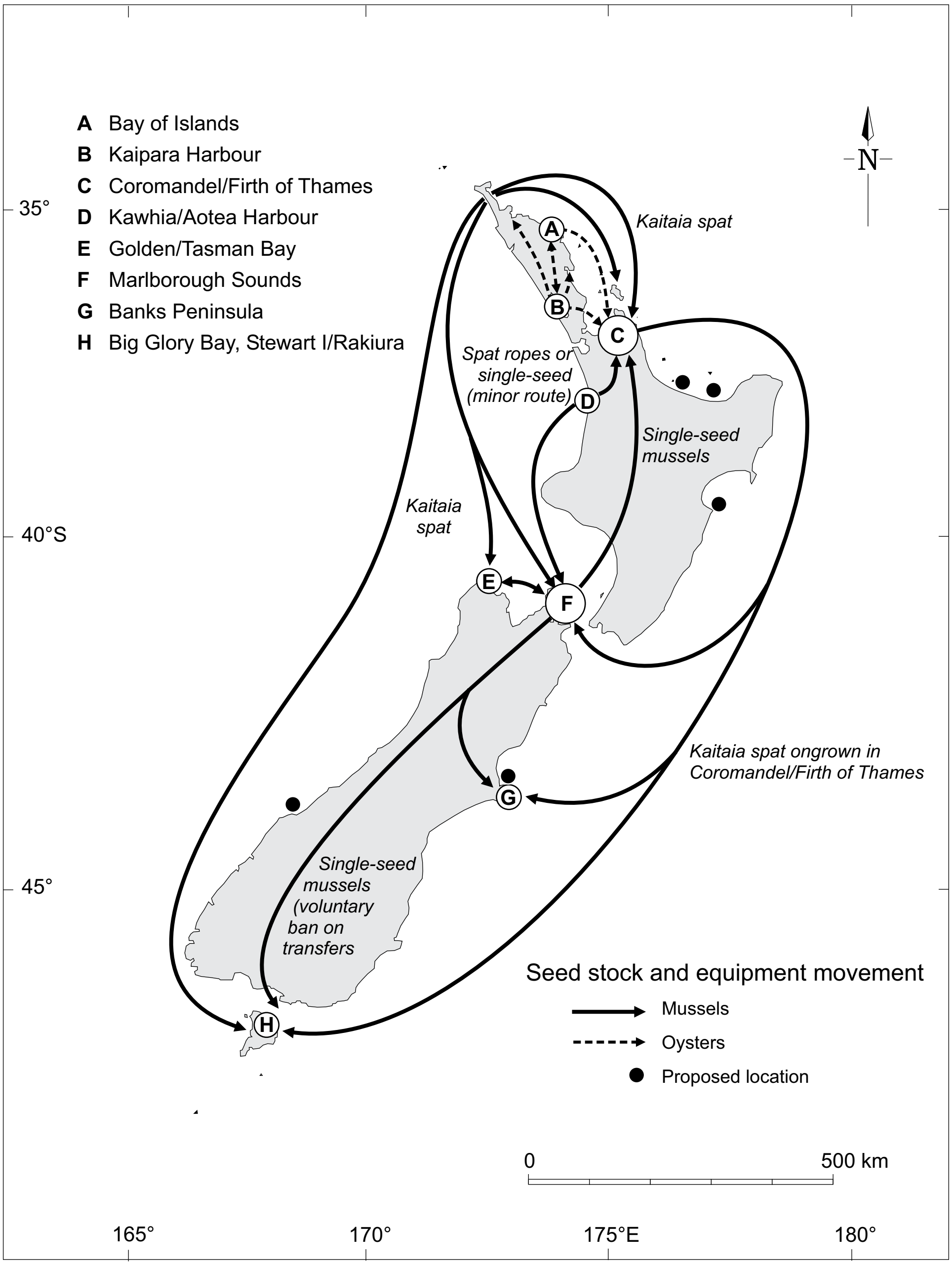

Figure 9. Existing (A–H) and proposed marine farming regions, showing the main pathways of equipment/vessels, Kaitaia mussel spat, seed-mussels and oysters around New Zealand. Bubble size for areas C and F indicates the greater intensity of aquaculture in these regions relative to other parts of New Zealand. Figure collated from figs 1 and 4 in Forrest & Blakemore (2002).

in Big Glory Bay is used to grow mussels, with a small area consented for salmon and flat oysters (*Ostrea* spp.).

A number of the large (hundreds to thousands of hectares) mussel farming blocks have recently received consent (e.g. Napier, and Pegasus Bay near Lyttelton), thus creating entirely new farming regions (Fig. 9). Similarly, MFish has recently given preliminary permission for a 45.5-ha farm to be located c. 1 km offshore in Jackson Bay, Westland (MFish 2006). In addition to mussel, oyster and fish farming activities, there are also a number of sea-based long-line paua farms in the Marlborough Sounds and in Akaroa Harbour on the south side of Banks Peninsula. Most other aquaculture activities consist of land-based paua or general hatchery operations. Most of these have coastal discharges and some are situated in relatively remote parts of the coastline (e.g. Wairarapa and Taranaki).

3.4.3 Marine farming pathways

The main inter-regional pathways for mussel and oyster aquaculture and related activities are summarised in Fig. 9. Within the mussel industry, spat associated with beach-cast seaweed at Ninety Mile Beach, northwest of Kaitaia (i.e. 'Kaitaia spat') supplies c. 70% of industry needs and is transferred to all farming regions. Inter-regional transfer of mussel spat on ropes or frames was relatively common in the past and still occurs between some regions, e.g. between Golden Bay and the Marlborough Sounds. An important feature of the industry from a biosecurity perspective is the transfer of small (c. 20–50-mm length) seed-mussels between growing regions (Fig. 9), which may also result in the incidental transfer of associated biofouling pests. To mitigate this risk, the New Zealand Mussel Industry Council Ltd (NZMIC) developed a voluntary code of practice for the main mussel farming regions, requiring that mussels transferred between them be de-clumped, washed and transported as 'single seed' (NZMIC 2001). This code aims to reduce the transfer of target species (e.g. *U. pinnatifida*, the ascidian *Ciona intestinalis* and, more recently, *Didemnum vexillum*), although it is apparent that fragments of bio-fouling or microscopic life-stages may survive the de-clumping and washing process (Forrest & Blakemore 2006). Because of such risks, mussel farmers in Big Glory Bay (Stewart Island/Rakiura) adopted a voluntary ban on the importation of mussel seed-stock from the Marlborough Sounds when the *U. pinnatifida* management programme was in place in southern New Zealand (Forrest & Blakemore 2002). Further details on mussel industry pathways can be found in Forrest & Blakemore (2002), which shows, for example, that inter-regional movements of mussel farm equipment and service vessels are relatively infrequent and, where they do occur, follow the same pathways as for spat and seed mussels.

Within the oyster farming industry, Kaipara Harbour, on the west coast north of Auckland, provides c. 70% of the year-round spat supply to farms in the northeast harbours and Coromandel area. Details of the spat movements are simplified in Fig. 9, but the transfer direction is generally west-to-east, as indicated. In addition to this movement of Kaipara spat, there are weekly transfers of adult oysters back to Kaipara Harbour from some of the east-coast sites, and weekly movements from the Bay of Islands to sites in the Coromandel. Intermittent movements of oysters may also occur in response to degraded water quality in rearing areas. These pathways are potentially high risk given the well-recognised role of oyster transfers in the spread of marine pests (see above). The oyster industry currently has no management plans to address bio-fouling organisms or other pests, although these are being formulated as part of a recent oyster farm development proposal for Kaipara Harbour (Taylor et al. 2005).

Sea-cage salmon farming is undertaken on Stewart Island/Rakiura and in the Marlborough Sounds. A different company operates within each region and there are generally no transfers between the two. Where cages have been transferred in the past, they have been completely refurbished (water/sand blasted and repainted) before re-deployment. Hence, with respect to national-scale transfers, biosecurity risks are minimal. However, the example of *Didemnum vexillum* in section 3.2.6 reveals risks associated with salmon cage transfers at a regional scale. The salmon stock used to supply the sea-cages is produced in freshwater hatcheries; thus they pose little risk in terms of the transfer of NIMS and, because of the change of environment from freshwater to marine, the risk of transfer of disease from hatcheries is negligible (TJD, pers. obs.). However, most of the land-based hatcheries for marine species (e.g. paua) that are scattered around the coastline have sea water intakes and discharges, and the marine biosecurity risk posed by such facilities is unknown.

3.5 OTHER PATHWAYS

There are a number of additional pathways by which marine pests could be spread around the New Zealand coastline, with a useful summary provided by Hewitt et al. (2004). It is important to be aware of these pathways so that their potential significance is not overshadowed by the obvious ones (e.g. hull fouling). Hence, rather than attempt a comprehensive review, we provide below examples that illustrate the diversity of possible mechanisms and the wide variety of marine species that are suited to human-mediated dispersal.

Trailer-borne pleasure boats are a potential pathway for the spread of NIMS. This could include, for example, planktonic organisms discharged in bilge water, or sediment-dwelling organisms that can inhabit the silt and mud adhered to anchors, hulls and outboard motors. In addition to risks associated with direct entry to HVAs, trailer-borne vessels (and probably the trailers themselves) carry the added risk of being able to transfer organisms between localities that are geographically separated, as has been described for the spread of freshwater macrophytes between New Zealand lakes (Johnstone et al. 1985). Busfield (2000) estimated that there were c. 300 000 boats in New Zealand, half of which were 5–7-m-long trailer power boats. This seems to be a substantial overestimate, however, as in 2002 there were 45 210 boat trailers of less than 2-tonnes capacity registered in New Zealand (Appendix 2). The national distribution of these is indicated in Fig. 10.

A large proportion of trailer-borne boats are used in the sea. The popular recreational boating areas in the North Island are the Bay of Islands, Hauraki Gulf, the Firth of Thames, Coromandel Peninsula, and Waitemata, Manukau and Kaipara Harbours. Around the South Island, most marine recreational boating is concentrated in the waters of Tasman and Golden Bays, and the Marlborough Sounds. With the exception of Kaipara Harbour and the Firth of Thames in the North Island, all these areas have marine reserves within them or in relatively close proximity. The potential for transfer of unwanted organisms may be considerably reduced if boat owners are educated on the risks posed by NIMS, and are encouraged to use wash-down facilities at launching ramps (when they are available) and ensure their boats are emptied of bilge water (BNZ 2005a; DOC 2005).

Additional potential vessel-related mechanisms include equipment, such as nets, lobster pots, ropes, floats, anchors and ground tackle[7]. For example, Sanderson (1997) noted that *U. pinnatifida* plants are often brought up in nets and suggested that anchors or fishing nets may be important mechanisms for spreading the seaweed to relatively remote parts of Tasmania. Along the Mediterranean coast, the highly invasive seaweed *Caulerpa taxifolia* may be spread by similar means,

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[7] Ground tackle: wires, ropes or chains attached to a vessel's anchor.

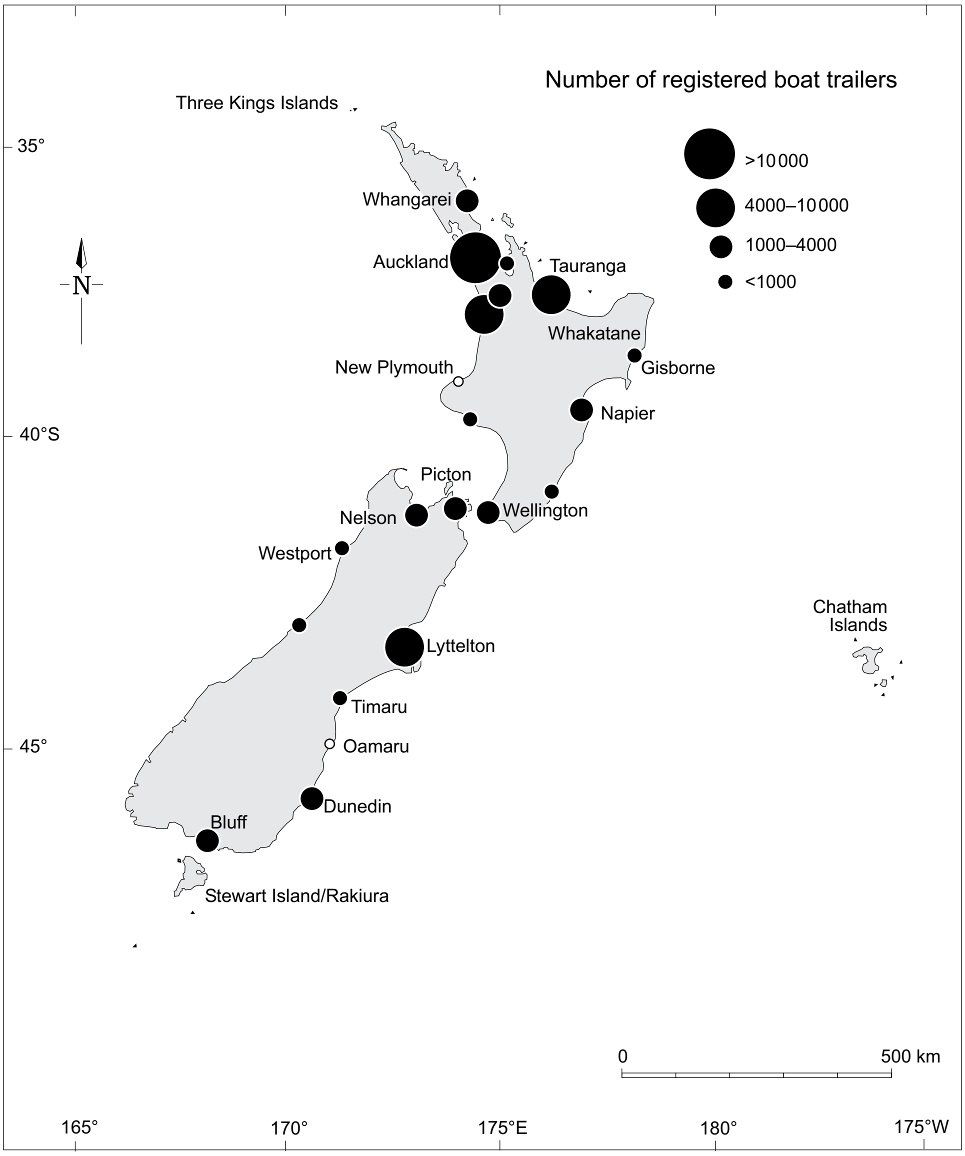


Figure 10. Distribution of registered boat trailers of under 2 tonnes capacity in New Zealand in 2002

since it is able to survive in the highly humid conditions that occur within boat anchor lockers and amongst heaped fishing nets (Sant et al. 1996).

Sea water contained in the keel centre cases of some types of ocean-going yachts arriving from the South Pacific islands has occasionally been found to contain small fish (G. Grant, Ministry of Agriculture and Forestry (MAF) Quarantine Service, pers. comm.). Although few of these vessels come to New Zealand, with only one or two visiting Whangarei each season (T. Hamilton, H & H Slipway Ltd, Whangarei, pers. comm.), they may still be a significant pathway for certain species, especially where adult life stages are transported. Similarly, overseas cruising yachts visiting New Zealand from areas outside the South Pacific could carry a variety of other organisms in their keel centre cases, which could be inadvertently released upon the vessel's arrival. Education of inspecting staff and the owners of these vessels about the possible presence of NIMS would be worthwhile.

Dredging and spoil disposal have been recognised as potential pathways for the spread of NIMS (Forrest et al. 1997). Although there are relatively few dredges in New Zealand, they are sometimes contracted to operate between ports and can carry with them sediments, which adhere to the areas around their hopper doors (TJD, pers. obs.). This material could readily be transferred from one locality to another during the course of dredging operations, carrying with it unwanted sediment-dwelling organisms, including cysts of toxic phytoplankton.

Diving equipment, including water trapped in wet suits, was recognised as a potential pathway for *U. pinnatifida* during eradication work conducted in Tasmania, leading to the adoption of a sterilisation procedure for dive equipment transferred between localities (C. Hewitt, MFish, pers. comm.). Rafting on flotsam may also be a pathway for NIMS, for example by the attachment of sessile organisms and small crustaceans to wood (Donlan & Nelson 2003) or plastic debris (Winston et al. 1996). In areas such as the Marlborough Sounds, it is not uncommon to find a variety of fouling organisms (including *U. pinnatifida*, *Ciona intestinalis* and various bryozoans) attached to beach-cast rope, floats and similar debris (BMF, pers. obs.).

The trade in marine species for the aquarium industry is another potential pathway for the introduction and spread of NIMS. The MAF Biosecurity Authority IHS for Ornamental Fish and Marine Invertebrates lists c. 117 genera of tropical marine fish and 69 genera of tropical marine invertebrates that may be imported into New Zealand (MAF 2002). It is unknown how many of these genera might be invasive, but the list and its implications should be viewed with the same concern as the list of exotic freshwater aquarium fish referred to by McDowall (2004) when he considered the implications of importing these fish to New Zealand.

The majority of species imported into New Zealand for marine aquaria are likely to be of tropical or sub-tropical origin and so unable to survive in any but the most northerly of the country's coastal waters; however, some pest species could survive and establish here. An example is the tropical green alga *Caulerpa taxifolia*, which initially evolved in an aquarium environment in Germany and was subsequently accidentally introduced into the Mediterranean Sea (Meinesz 1999). Once there, it spread widely, forming dense carpets over large areas, competing with native marine algae and seagrasses, and displacing invertebrates (Nelson & Broom 2002). *Caulerpa taxifolia* has also been found in Tunisia, Florida, California and Australia, and was recently recorded from a saltwater aquarium in New Zealand although DNA analyses showed that in this case it was not the invasive Mediterranean strain (Nelson & Broom 2002). *Caulerpa taxifolia* has been declared unwanted and notifiable in New Zealand; thus importation of any strain is prohibited. Specimens of the genus *Caulerpa* can be obtained via the internet, although it is uncertain whether any of these are *C. taxifolia* (MFish 2001).

4. Assessing pathway risk

4.1 IDENTIFYING PATHWAY INFORMATION REQUIREMENTS

The pathway information presented in this document primarily has a national focus, except for a few examples (e.g. for tourist and cruise vessels) where information is presented or discussed in relation to specific HVAs. As outlined in section 2, collection of detailed information on human-mediated pathways at a regional scale is a significant task that was beyond the scope and budget of the present study, and not justified in the absence of a definitive list of conservation-based HVAs. There is a need, therefore, to define such areas in a defensible and transparent way. In this respect, selection criteria have been discussed elsewhere (e.g. Inglis 2001), and Biosecurity New Zealand has funded projects to characterise environmental, social, cultural and economic values around the entire New Zealand coastline. Such studies will undoubtedly assist in the definition of conservation-based HVAs.

Following the approach proposed by Forrest et al. (2006), the definition of conservation-based HVAs would then lead to a consideration of high-risk species that threaten those values; the potential distribution of such organisms in relation to HVAs; and the potential pathways of spread of high-risk organisms to priority areas. Subsequent decisions around priorities for management of pathways will then need to consider (among other things) the spatial scales at which this is feasible, which in turn will determine the spatial scale at which information on human-mediated pathways is obtained. With regard to the management of pathways for *U. pinnatifida*, for example, Forrest & Blakemore (2002) suggested (in relation to aquaculture) that effort should be directed towards identifying and managing high-risk pathways linking the main aquaculture regions. While the Marlborough Sounds was recognised as the most significant and extensive marine farming area, the argument against undertaking a detailed analysis of marine farming pathways in that region was that *U. pinnatifida* was already widely established. Consequently, any uninfested sub-regions (e.g. bays) were probably vulnerable to natural spread, including conservation-based HVAs such as the Long Island-Kokomohua Marine Reserve in Queen Charlotte Sound. Furthermore, a surveillance programme of the intensity required to track the distribution of *U. pinnatifida* within the region and to determine whether or not uninfested areas existed was not considered to be feasible.

In contrast, the example of *Didemnum vexillum* (see section 3.2.6) highlights a situation where a barge resulted in the long-distance domestic translocation of a potentially significant fouling pest, after which an aquaculture transfer within a region resulted in the movement of the organism from a relatively confined location to a valuable marine farming area. The marine farming area was not particularly vulnerable to the natural spread of *D. vexillum*, as this species has a restricted natural dispersal capacity and establishes mainly on artificial structures; consequently, its spread is primarily human-mediated (Coutts & Forrest 2007). Therefore, management of human-mediated pathways within specific regions (e.g. across scales of kilometres to tens of kilometres) could be a highly effective control mechanism for this species, and surveillance concentrated on artificial structures within these regions is realistic.

These examples highlight that the utility of information on human-mediated pathways will in part depend on the proximity of selected HVAs to donor regions for actual or potential pests, in relation to the known distribution and biological characteristics of target organisms. Clearly, if an HVA is vulnerable to uncontrolled spread via natural mechanisms within a short time, there may be little point in undertaking a detailed analysis of human-mediated pathways, since the information would have limited use from a management perspective. Presumably, natural spread to HVAs is more likely when they are adjacent to shipping ports rather than when they are in remote locations, such as the subantarctic islands. However, at intermediate spatial scales, the differences may be less obvious. Therefore, Forrest et al. (2006) describe a decision tree that can be used as a guide for determining the likely importance of natural v. human-mediated spread in relative terms. The development and application of generic spread models could assist this type of assessment and also aid prediction; for example, by identifying pathway management requirements under different infestation states for donor areas. There are a number of examples from terrestrial weed management and epidemiological studies that could be adapted for this purpose (e.g. Korobeinikov et al. 2000) and progress has recently been made in New Zealand with the development of regional spread models for marine pests (e.g. Acosta et al. 2006).

4.2 PATHWAY RISK

For HVAs where human-mediated pathway information needs have been identified, it should be acknowledged that even for well-known transfer mechanisms, activity can be unpredictable and variable in space and time, making it difficult to generalise about the pathways and their associated risks. In relation to the movement of vessels, this was highlighted for fishing boats (section 3.2.4) and moored recreational craft (section 3.2.5). Similarly, for aquaculture pathways, the extent and type of movements of shellfish seed-stock, for example, is dictated by regional supply and demand, which changes from year to year and between regions. While it is usually possible to determine major pathways and identify important information gaps or areas of uncertainty, experience has shown that unexpected events can pose significant risks in some circumstances (e.g. Hay & Dodgshun 1997; Coutts 2002). This problem is compounded where pathways are obscure or unrecognised. For example, the translocation of species on flotsam is a chance event that could nonetheless undermine attempts to manage human-mediated introductions to HVAs.

Despite such issues, it is still important that key pathways are identified, their risks assessed and the level of uncertainty acknowledged. Once the relative importance of various pathways for high-risk organisms have been identified, management efforts should be directed towards pathways where the benefits of risk reduction are greatest, and where management is feasible and affordable.

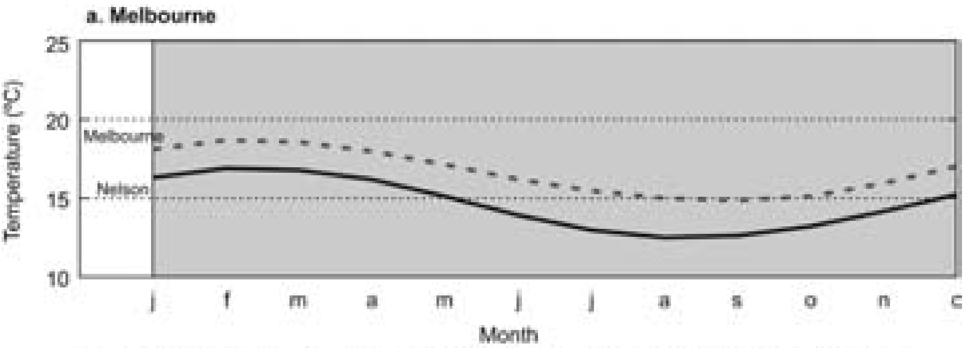
When defining the spatial scale at which information on human-mediated pathways is required for a given HVA, it is important to consider the level of detail and quantification required to assess pathway risk. A comprehensive understanding requires considerable knowledge and detailed quantitative analyses of the infection pathway at source, survivorship during transport, likelihood of release, and subsequent survivorship and establishment. To date, such approaches have been undertaken only in relation to particular pathways, such as ballast water introductions to Australia (e.g. Hayes & Hewitt 1998), or for multiple pathways to spatially defined regions, such as the Tasman-Golden Bay area in the Nelson region (Acosta et al. 2006).

These quantitative approaches highlight the complexity of pathway risk assessment. For the purpose of more broadly assessing risks across multiple HVAs, species and pathways, Forrest et al. (2006) proposed a semi-quantitative approach using relative scores for the likelihood of human-mediated introduction, which are, in turn, developed from basic pathway information and expert judgement. They suggest that, as a minimum, an effort should be made to determine the likelihood of introduction via major pathways such as ballast water, hull fouling, aquaculture and natural spread. Using this basic approach, pathway risk could be assessed with reference to key factors such as frequency/volume of movements, the timing of activity and the characteristics of target organisms that may be carried. For example, while *U. pinnatifida* may be spread via ballast water, evidence suggests that fouling is likely to be by far the most important inter-regional mechanism of spread (e.g. Hay 1990). In turn, fouling as a transfer mechanism for *U. pinnatifida* is likely to be most important under specific conditions, such as for vessels or structures that are not adequately maintained, that move to HVAs at a time of year when *U. pinnatifida* is mature, or that remain in HVAs long enough for maturity to be reached and spores to be released (Sinner et al. 2000).

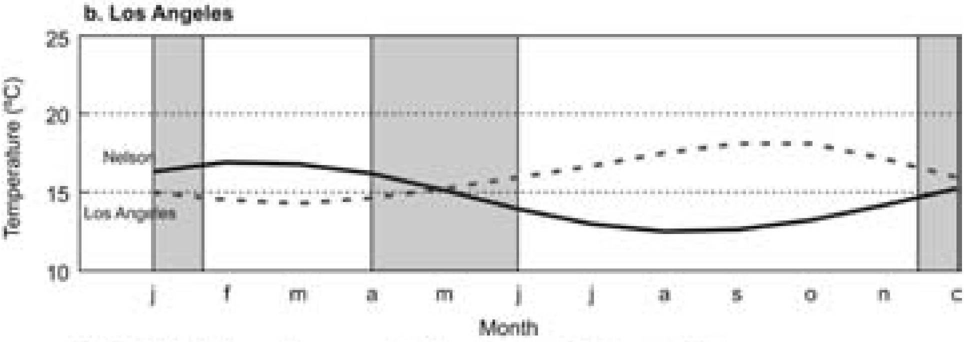
The GIS-based package 'Shipping Explorer' (Taylor 2002) is an example of a support tool that could be applied in pathway risk assessment (although only in relation to international ballast water pathways at this stage of development). Figure 11 shows an example output from 'Shipping Explorer'; in this instance, the environmental match between three source ports and Port Nelson is depicted, and invasion windows are identified for species on the Biosecurity New Zealand list of unwanted marine organisms (assuming that life-stages suited to ballast transport are present in the source port). For illustrative purposes (i.e. that are not necessarily biologically meaningful), these windows are assumed to occur in situations where sea surface temperatures between source and recipient regions differ by ≤ 2°C; hence they will be more commonly shared between ports on similar latitudes (as in the case of Melbourne and Nelson). The substantial pathway activity and diversity in the Nelson region makes it highly likely that an unmanaged incursion into the port would lead to the spread of high-risk species to adjacent localities of high value. This relatively crude assessment based on temperature matching could be refined by further queries within the 'Shipping Explorer' database. For example, in-transit ballast water temperature profiles could be extracted to assist assessment of the survivorship of the high-risk species en route. With further development, the environmental matching approach could be expanded to include a wider range of environmental variables, such as salinity and habitat type.

For all models and databases, it is important that information on changes to risk pathways is regularly updated, particularly when new pathways emerge.

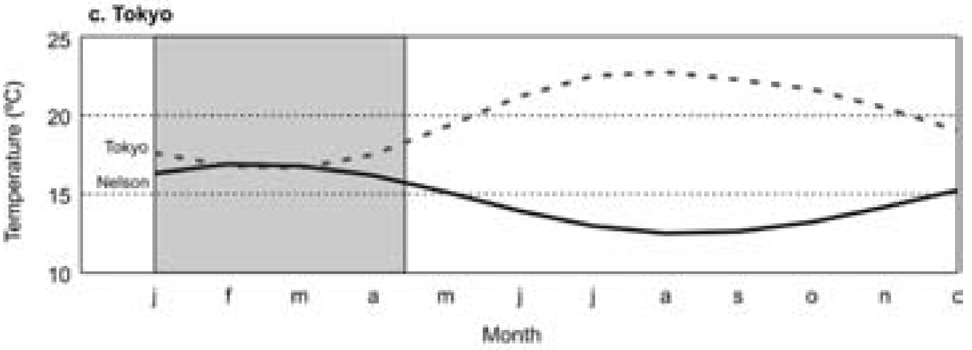
Figure 11. Environmental matching between international source ports and Port Nelson, New Zealand. High-risk species on the Ministry of Fisheries (MFish) marine pest list that are present in the source ports are indicated, with shading used to highlight potential invasion windows for these species based on an illustrative difference in port sea surface temperatures of 2°C.



MFish high risk species present in Melbourne: *Asterias amurensis, Sabella spallazanii, Carcinus maenas, Gymnodinium catenatum*



MFish high risk species present in Los Angeles: *Caulerpa taxifolia*



MFish high risk species present in Tokyo: *Asterias amurensis, Carcinus maenas, Gymnodinium catenatum, Caulerpa taxifolia, Potamocorbula amurensis*

As described by Forrest & Blakemore (2002), significant new pathway risks may emerge for particular NIMS where any of the following situations arise: the infestation of pest-free source regions whose existing pathways lead to uninfested areas or areas where the pest is managed; the emergence of new pathways from infested areas to existing areas that are currently uninfested (e.g. most of the example HVAs referred to in this report); and the development of new pathways from infested areas to new areas that are currently uninfested. Clearly, pathway risks may also change over time within these broad categories. For example, an increase in pest density within a donor region may increase the risk that pathways become infested, on the basis that inoculation pressure (e.g. density of larvae or spores and frequency of release) is a primary correlate of invasion success (Ruiz et al. 2000; Floerl & Inglis 2005; Lockwood et al. 2005; Verling et al. 2005).

4.3 FUTURE DEVELOPMENTS

For the protection of New Zealand's conservation values from NIMS, an agreed set of HVAs must be developed, since this is critical to the identification of management priorities and the information linked to them. The development of such a list should be accompanied by the identification of target pests that are of greatest concern from a conservation perspective, and an assessment of their potential distribution and thus the HVAs at risk. The development of a 'next pest' list, which is currently being undertaken by Biosecurity New Zealand, should be helpful in this respect. Similarly, a series of projects that are being funded by Biosecurity New Zealand will determine hull fouling risks associated with different vessel types at a national scale, providing a knowledge base that will be useful in pathway risk assessment. However, the identification of high-value areas at a regional level will mean further information is needed on pathways for specific HVAs. This could involve targeted, field-based surveys of human-mediated pathways and an assessment of the risks of natural spread. For some regions, such as Tasman-Golden Bay, this type of analysis has already been conducted (Acosta et al. 2006).

The process of determining biosecurity management priorities for conservation could be assisted by the further development of appropriate risk management approaches, such as that proposed by Forrest et al. (2006). The assessment process in this framework involves assigning the values for each of a series of 'site-species' combinations according to the likelihood of events (including pathway risk) that cause a pest infestation, the magnitude of its consequences, and the feasibility and effectiveness of management. The framework provides a comparison between the threat posed by unmanaged risks and the reduced threat posed by managed risks, and accounts for the costs of risk management. Since the framework promotes a 'site-species' approach, the analyses to determine risk could involve a significant undertaking when multiple species and HVAs are being considered. Hence, further development is likely to involve case studies to validate the logic of the framework, followed by computer-based automation of the process and the analyses that support it. We also intend for this approach to be expanded through further development of a Relative Risk Model that was recently applied to the Firth of Thames Ramsar site (Elmetri & Felsing 2006) and related risk assessment methods (e.g. Elmetri et al. 2006), to provide tools for evaluation of biosecurity issues within the context of broader environmental risk.

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7. Glossary

BNZ	Biosecurity New Zealand
DOC	Department of Conservation
GRT	Gross Registered Tonnes
HVA	High-value area
IHS	Import Health Standard
IMO	International Maritime Organisation
LOA	Length overall
MAF	Ministry of Agriculture and Forestry
MFish	Ministry of Fisheries
NIMS	Non-indigenous marine species
Pathway	Mechanism of spread of non-indigenous marine species (NIMS) to new locations (e.g. water currents, ballast water or hull fouling)

Appendix 1

PASSENGER VESSELS VISITING FIORDLAND

Name, length overall (LOA), gross registered tons (GRT), passenger capacity, locations visited (Y = yes; N = no; NR = not recorded; F = listed as visiting Fiordland, but exact localities not stated), and number of scheduled trips for passenger vessels visiting Fiordland from December 2000 to May 2002. Vessels sorted by size (GRT). Information sources: K. Swinney, Environment Southland, pers. comm.; Port of Otago website www.portotago.co.nz; and Lyttelton Port Company website www.lpc.co.nz.

VESSEL	LOA	GRT	PASSENGER CAPACITY	VIA HOBART?	DOUBTFUL SOUND	MILFORD SOUND	DUSKY SOUND	SCHEDULED TRIPS	
								2001	2002
Regal Princess	245.10	69 845	1900	Y	N	Y	N	2	1
Legend of the Seas	264.00	69 130	1750	Y	Y	N	Y	NR	7
Queen Elizabeth 2	293.52	66 852	1970	N	Y	Y	N	0	1
Amsterdam	237.86	60 874	1380	NR	Y	Y	Y	NR	1
Pacific Sky	240.30	46 087	1212	N	N	Y	N	NR	2
Norwegian Wind	190.00	39 500	1200	Y	N	Y	Y	NR	4
Crown Odyssey	187.71	34 242	1052	N	Y	Y	Y	0	1
Asuka	190.00	28 717	584	N	F	F	F	0	1
Silver Shadow	182.00	25 000	396	Y	Y	Y	Y	1	2
Clipper Odyssey	102.96	5 218	120	Y	Y	Y	Y	NR	4
Total visits								**3**	**24**

Appendix 2

REGISTERED FISHING VESSELS, MOORINGS AND TRAILER-BORNE VESSELS THROUGHOUT NEW ZEALAND

Mooring data grouped by main town/city; trailer data* by postal district.

LOCATION	FISHING VESSELS	MOORINGS	REGISTERED TRAILERS
Bluff	173	–	1557
Gore	5	–	–
Balclutha	8	–	–
Taieri	8	–	–
Dunedin	40	120	2135
Oamaru	15	–	346
Timaru	30	–	790
Christchurch (Banks Peninsula)	60	93	4286
Cheviot/North Pegasus Bay	7	–	–
Kaikoura	46	–	–
Marlborough Sounds	106	1040	887
Motueka	–	75	–
Tasman Bay (Nelson)	108	480	1704
Westport	15	–	55
Greymouth and Hokitika	40	–	280
Fox	3	–	–
Haast	19	–	–
Milford Sound	18	–	–
Doubtful Sound	3	–	–
Chatham Islands	65	–	–
Cape Campbell	5	–	–
Wellington	49	–	2320
Masterton/Riverton	28	–	234
Napier	55	122	1424
Gisborne	44	–	509
Whakatane (Bay of Plenty)	21	–	–
Tauranga	87	1060	4003
Whangamata (South Coromandel)	45	415	999
Coromandel Peninsula (North Coromandel)	18	–	–
Thames	30	–	–
Auckland	104	5197	14705
North Shore	28	–	–
Whangarei	65	429	2730
Bay of Islands	12	–	–
Mangonui	41	90	–
Houhora Harbour	23	–	–
North Cape	2	–	–
Herekino	10	–	–

Continued on next page

Appendix 2—continued

LOCATION	FISHING VESSELS	MOORINGS	REGISTERED TRAILERS
Hokianga	7	-	-
Kaipara	60	-	-
Manukau	49	-	-
Kawhia Harbour	25	-	5012
New Plymouth	17	-	821
Whanganui	18	-	413
Totals	**1629**	**9229**	**45 210**

[*] Source: Kheang Chrun, Transport Registry Centre, Land Transport Safety Authority of New Zealand (pers. comm.).