NIWA

Taihoro Nukurangi

Criteria for selecting New Zealand ports and other points of entry that have a high risk of invasion by new exotic marine organisms

Graeme J. Inglis

Final Research Report for Ministry of Fisheries Research Project ZBS2000/04 Objectives 1 & 2

National Institute of Water and Atmospheric Research

August 2001

Final Research Report

Report Title:	Criteria for selecting New Zealand ports and other points of entry that have a high risk of invasion by new exotic marine organisms
Authors:	Graeme J. Inglis
Date:	August 2001
Contractor:	NIWA
Project Title:	Surveillance for exotic marine organisms in New Zealand's ports and other high risk points of entry
Project Code:	ZBS2000/04 (Objectives 1 & 2)
Project Leader:	Graeme J. Inglis
Duration of Project:	
Start date:	30/04/01
Completion date:	30/08/01

Executive Summary

The objectives of this project were:

1. To develop criteria for selecting ports and other points of entry that have a high risk of invasion by new exotic marine organisms.

2. To make recommendations on the location and priority of sites to be included in an ongoing surveillance regime (using the criteria from objective 1).

In this report, I reviewed a range of published and unpublished information to develop risk profiles for New Zealand's major points of entry for international shipping. These sources included:

- existing data and international scientific literature on the patterns of distribution and spread of non-indigenous marine species,
- relevant international, national and regional policy and legislation,
- existing databases on the patterns of trade and movement of commercial and non-commercial vessels into New Zealand,
- data on reported volumes and sources of ballast water discharged at New Zealand ports, and
- preliminary consultation with relevant industry sectors and experts.

Potential indicators of incursion risk associated with patterns of international shipping into New Zealand were identified from existing studies. Where possible, I calibrated these indicators for specific points of entry in New Zealand using existing databases on the size, type, port of origin, history of ballast discharge and port of entry of vessels entering New Zealand waters. These sources were used to provide textual and quantitative summaries of the risk profiles of New Zealand's major ports of entry. Multivariate ordination and classification procedures were then used to provide preliminary statistical characterisations of risk classes of the points of entry. Additional, qualitative selection criteria were incorporated to provide final recommendations for the selection of surveillance sites.
Ports were classified into four generic risk classes on the basis of existing shipping patterns:

1. Ports that received large numbers of merchant vessels and large numbers of pleasure craft from a wide range of source countries, but which received a small volume of discharged ballast, and a relatively small number of discharge events.
2. Ports that received moderate numbers of merchant vessels and moderate numbers of pleasure craft from a small number of source countries, and which received a small volume of discharged ballast and a small number of discharge events.
3. Ports that received small numbers of pleasure craft, a moderate number of merchant vessels from a large numbers of source countries, and which received a large volume of discharged ballast from a large number of ballast discharge events; and
4. Ports that received small numbers of merchant vessels, small numbers of pleasure craft from few source countries, and which received a moderate volume of discharged ballast from a moderate number of ballast discharge events.

NIWA's intention is to use baseline surveys of the ports to test the risk characterisation described above so that future surveillance work can be developed adaptively and refined according to the areas of greatest risk. In the report, I have recommended an initial list of 17 points of entry that should be surveyed over the next two years. These constitute ports that are considered both relatively high and moderate risk points of entry under the classification scheme.

Table of Contents

Introduction

1.1 Designing Surveillance Programme for Non-indigenous Species (NIS)

Surveillance is an integral part of pest control. In the biosecurity context, it is a specialised form of monitoring that is intended to detect critical events during the introduction and spread of unwanted species. Experience shows that successful eradication and control programmes for unwanted species depend upon early detection of populations, while they are still relatively small and isolated (Moody and Mack 1988, Culver and Kuris 2000, Field 1999). The accelerating global spread of non-indigenous species (NIS) in marine environments and growing recognition of their impacts on native ecosystems have highlighted the need for comprehensive surveillance programmes to detect unwanted species before they endanger native marine environments (Ruiz et al. 1997, 2000). The design of such programmes is not a trivial issue. At an early stage of establishment, populations of NIS are likely to be sparse, aggregated, and to contain a large proportion of immature individuals, making them easy to miss using conventional sampling designs.

There is currently limited international experience in developing surveillance networks for marine NIS. In Australia, general protocols have been developed for the design of port surveys and baseline surveys for NIS have been undertaken at 26 major ports (Hewitt and Martin, 2001). Port surveys have also been initiated by the International Maritime Organisation (IMO), in association with the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), at six demonstration sites throughout the world (Global Ballast Water Management Programme 2001). The six ports – Sepetiba (Brazil), Dalian (China), Mumbai (India), Kharg Island (Iran), Saldanha (South Africa) and Odessa (Ukraine) – will undergo comprehensive ballast water risk assessments and baseline surveys for existing indigenous and non-indigenous species. Baseline surveys are also underway at selected ports in the United Kingdom and USA. It is important that initiatives in New Zealand complement the existing international surveys so that information can be shared effectively on high risk species and pathways of establishment.

2 Surveillance for NIS in New Zealand's coastal waters.

The Ministry of Fisheries has proposed a surveillance network for marine NIS in New Zealand that consists of three types of sampling locations:

Points of Entry – where NIS are likely to be introduced and establish founding populations;

High Risk/Sentinel Sites - natural habitats that are at greatest risk of initial establishment by NIS. (Typically, natural environments within the dispersal distance of the site of introduction or founder populations); and

High Value Sites - where the impacts of NIS are likely to be greatest if they become established.

The purpose of this project is to develop a rationale for selecting locations in the first category of sampling sites: points of entry. Criteria for selecting High Risk/Sentinel sites and High Value sites have been developed in a separate project (ZBS2000/01A, Inglis 2001). This report identifies and evaluates risk criteria associated with major points of entry for marine NIS into New Zealand and makes recommendations for the prioritisation of surveillance sites.

3 Methods

To develop profiles for high risk points of entry by NIS into New Zealand, I reviewed published national and international literature on the introduction and spread of marine NIS. Summaries of these studies were then used to identify potential indicators of incursion risk associated with patterns of international shipping into New Zealand. Where possible, these indicators were calibrated for specific points of entry into the country using data obtained from published literature and from existing databases. Data on the size, type, port of origin, history of ballast discharge and port of entry of vessels entering New Zealand waters are contained in databases held by MFish, NZ Customs and MAF Quarantine Service. Statistics New Zealand and the Port Companies hold additional information on the trading volumes and activities of different ports. These sources were used to provide textual and quantitative summaries of the risk profiles of New Zealand's major ports of entry. Multivariate ordination and classification procedures were then used to provide preliminary statistical characterisations of risk classes of the points of entry. Additional, qualitative selection criteria were incorporated to provide final recommendations for the selection of surveillance sites.

3.1 Limitations of the data sets

3.1.1 Ballast water database (Source: MFish)

Under Section 22 of *The Biosecurity Act 1993*, ballasted vessels arriving in New Zealand are required to complete a reporting form that details the volumes and origin of ballast carried by the vessel, and its recent history of hull maintenance. Part 2 of the form provides more detailed information on ballast exchange and discharge and is to be completed by vessels that discharge ballast water while in New Zealand. Completed forms are collated and the information archived in a database that is managed by the Ministry of Fisheries. The Ministry supplied NIWA with a copy of the ballast water database and contents to prepare this report. It contained records that spanned 1998 to 2000, but a complete 12 month period of records was available only for 1999.

Hay *et al.* (1997) have discussed some of the general limitations of the reporting forms for estimating the risks of ballast discharge. The version of the ballast database that we received had a number of structural and data errors and, at the time of writing, was being corrected by MFish personnel. The time constraints on this project meant that it was not possible to use the officially corrected version of the data or database, so NIWA undertook some preliminary data correction and checking prior to extracting summary information. For example, most numeric variables (e.g. total ballast capacity, total ballast carried, discharge volumes, etc) and some dates in the database were stored as character fields rather than numeric or date fields. This made extraction of data summaries difficult. We amended all numeric, date and geo-position fields to the most appropriate data type to allow summaries to be made.

There were also numerous errors in data entry. Many of these appeared to be of little significance to the purpose of this study and were easily corrected. For example, there were up to 50 duplicate records in the database. Vessel categories and port codes were also not standardised. NIWA re-coded vessels into one of 11 different categories (Bulk, Tanker, RoRo, LPG Tanker, Chemical Tanker, Container, General Cargo, Reefer, Passenger, Fishing, and Other) to allow more consistent extraction of data summaries. Where it was possible to identify the source ports and ports of arrival of the vessel, we amended the incorrect port and country codes (see also Section 5.6). In some instances, we were able to cross-validate the data against other sources of information (see sections 5.5 and 5.6), but because of the inadequacies of the data and the database, the data summaries should be treated as only indicative of general patterns of risk rather than absolute measures.

3.1.2 Customs & Immigration data

The NZ Quarantine Service supplied NIWA with summary data on small craft arrivals into New Zealand. This information was extracted from Customs and Immigration data that are collected from vessel masters on their arrival in New Zealand. The summaries we received did not distinguish the port of entry from the designated port of departure for each vessel, but instead indicated total vessel movements in each port. Also, information provided by the Quarantine service was summarised according to the geographic location of the customs office closest to the port and, therefore, reflected the location of the nearest administrative centre, rather than the specific port at which the vessel arrived or departed. It was not possible, therefore, to identify vessel movements into, or out of, particular marinas or berthages within the general customs regions using these data.

4 Pathways of entry into New Zealand

The most common contemporary means of introduction of NIS in marine environments is by ship-borne transport in ballast water and as fouling assemblages on the hulls of vessels (Carlton 1985; Ruiz *et al.* 2000) and other submerged structures that are imported into New Zealand (Foster and Willan 1979). Alternative pathways of transfer, such as the release of species for fisheries and aquaculture, or escape of aquarium species, account for a much smaller proportion of known establishments (Cranfield *et al.* 1998; Ruiz *et al.* 2000). Most new incursions, therefore, appear to be associated with major seaports and other points of entry for international vessels (Ruiz *et al.* 1997, 2000). As an isolated island nation that has no common coastal borders with other countries, and where the arrival of invasive species by natural dispersal mechanisms is unlikely (Stanton 1998), major shipping ports have been, and are likely to continue to be important foci for the establishment of NIS in New Zealand (Cranfield *et al.* 1998)

Major commercial shipping ports and ports of entry for vessels entering New Zealand's territorial waters are shown in Fig. 1. More than 99% of the volume of goods exported from, and imported into New Zealand is carried by sea. The volume of cargo, and by association, the number and size of international vessels entering New Zealand continues to grow. Between 1991 and 2000, the gross weight of cargo unloaded in New Zealand ports increased by almost 70% to around 13.6 million tonnes (Statistics New Zealand 2000). Markets for these goods have diversified considerably. Today, over half of New Zealand's overseas trade is with South-East Asia and Australia, but a broad range of other countries in the Asia-Pacific region and Europe make up the remainder.

Not all vessels that enter New Zealand waters are merchant cargo vessels. Since the 1970's, many of New Zealand's major fishing companies have chartered foreign vessels on a seasonal basis. Increasing numbers of private pleasure craft and passenger cruise liners are also entering New Zealand's waters. These vessels are required to call first at one of 18 ports of entry to clear customs and immigration procedures. The designated ports of entry are: Opua, Whangarei, Auckland, Onehunga, Mount Maunganui, Taharoa Terminal, Gisborne, New Plymouth, Napier, Wellington, Picton, Nelson, Westport, Lyttelton, Timaru, Port Chalmers, Dunedin, and Bluff (Fig. 1).

5 Indicators of incursion risk

Sites used for surveillance must optimise available resources and should, therefore, be located where they are likely to achieve the greatest results. In most instances, this will be where there is the greatest likelihood of an incursion. Despite growing research into the characteristics of successful invaders and their impacts, many aspects of biological invasions remain unpredictable (Ruiz et al. 1997; 2000; Cranfield et al. 1998; Mack et al. 2000; Kolar and Lodge 2001). In particular, it is difficult to predict with any accuracy which species will invade, and where and when they will establish. Existing studies show considerable geographic variation in invasion characteristics, even for the same species (Carlton 1996; Grosholz and Ruiz 1996; Ruiz et al. 1997; 1999; 2000; Mack et al. 2000). This uncertainty makes it difficult to identify high risk locations precisely. Nevertheless, some general risk profiles have emerged from existing literature that are useful for prioritising potential surveillance sites.

Two major influences on the rate of establishment of non-indigenous species (NIS) are recognised:

- the supply of colonizing stages to new environments ("propagule supply"), and
- the susceptibility of the environment to invasion (Lonsdale 1999, Mack *et al.* 2000, Ruiz *et al.* 2000).

5.1 Propagule supply

Establishment is most likely when a sufficiently large number of potential colonists arrive at a time when environmental conditions at the recipient site are conducive to the survival of adult or resting stages. Propagule supply hypotheses suggest that the likelihood of such an event is a function of the total number of individuals that arrive in a region over a given period of time. Their basic tenet is that the chances of successful establishment increase in proportion to the number of arriving individuals ("propagule pressure"), an assumption that is supported by historical planned introductions of NIS into

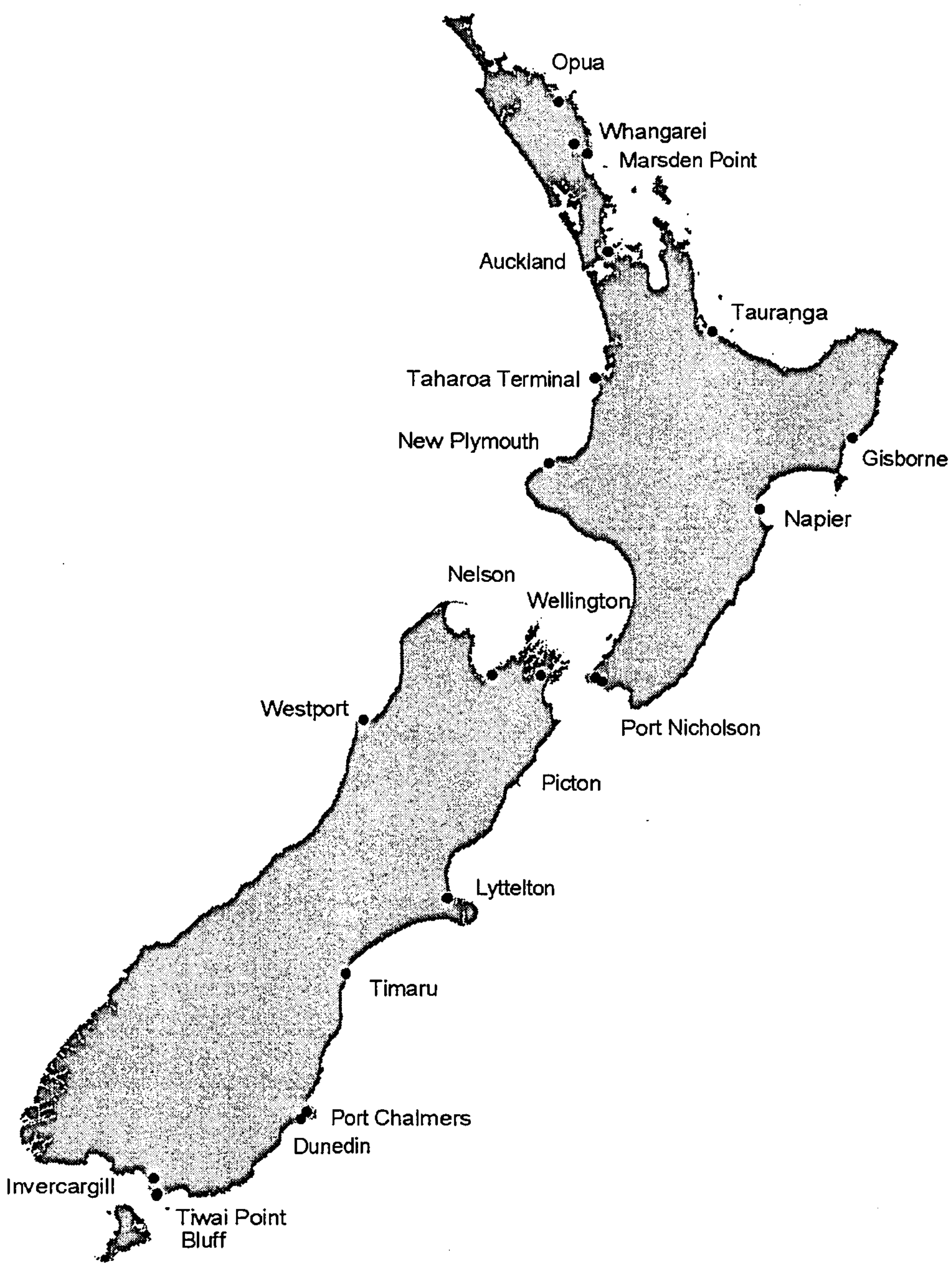


Figure 1. Location of major ports and other points of entry into New Zealand for international shipping.

New Zealand and elsewhere (Veltman *et al.* 1996, Forsyth and Duncan 2001). However, other components of propagule supply may have an equally important influence on the success of establishment. These include the relative viability and availability of colonizing stages, and their rate of delivery to a new area in space and time.

"Propagule supply" is, therefore, a function of:

- the total abundance of individual NIS that enter the area,
- the frequency with which they are introduced,
- the duration and timing of their exposure to local habitats, and
- the physiological and behavioural viability of the colonizing stages in the new environment.

5.2 Site susceptibility

Site susceptibility, on the other hand, is influenced by the biotic and abiotic environment of the recipient site, including the prevailing abiotic conditions, the availability of resources, and the abundance of natural competitors and predators (Stachowicz *et al.* 1999, Mack *et al.* 2000, Ruiz *et al.* 2000). Survival is most likely where conditions at the recipient site closely match those of the species' home range and are within the limits of tolerance of the most sensitive stages of its life-history (Ruiz *et al.* 2000). Thus, the environment in which colonizing propagules arrive also has an important influence on their viability.

Carlton (1996) identified a number of other circumstances that affect the susceptibility of recipient sites to invasion. Natural and anthropogenic disturbances that increase the availability of habitat to colonizers can provide important "windows of opportunity" for establishment. Disturbances that create new, unoccupied habitat (e.g. wharves, breakwalls, jetties, pilings), or that change the abundance and distributions of native species (e.g. dredging, sedimentation, eutrophication, exploitation, chemical pollution, etc) provide opportunities for NIS (Lonsdale 1999). For example, rapid colonisation of San Francisco Bay by the Asian clam *Potamocorbula amurensis* has been attributed to depression of the native biota by unusually large floods (Nichols *et al.* 1990).

5.3 Indicators of propagule supply and site susceptibility

It is difficult to measure propagule supply and site susceptibility directly, since these are likely to exhibit large geographic, temporal and taxon-specific variation. Nevertheless, generic indicators of risk can be derived from existing literature. As the major pathways for the introduction of marine NIS are via ballast water discharge or hull-fouling, indicators of risk should be broadly related to the patterns of movement of vessels entering New Zealand waters. Potential indicators related to shipping movements are presented in Table 1.

These indicators should be considered only cursory measures of risk, since they are largely untested for contemporary introductions of marine species. By incorporating them into the overall design of surveillance programmes it will be possible to test their efficacy for predicting patterns of incursion against field data.

5.4 Number and type of vessel visits

5.4.1 Ballasted vessels

Table 2 summarises the total number of arrivals of each vessel type in each New Zealand port during 1999. Auckland was the port of arrival for almost ½ of all vessel visits in 1999 and recorded the largest diversity of vessel types. Most of the traffic into Auckland (77% of visits) consisted of freighters for general goods (i.e. Container, General Cargo, Reefer and RoRo vessels), which carry and discharge relatively small volumes of ballast water (see section 5.5). Many of these cargo lines visit Auckland as their first port of call into New Zealand before travelling to other locations throughout the country. Christchurch and Invercargill (Bluff) are the main hub container ports for the South Island. Other major destinations for international vessel arrivals include, in decreasing numeric order: Tauranga, New

Plymouth, and Whangarei (including Marsden Point). Tauranga, Auckland, Whangarei, Christchurch, Napier and Invercargill export and import significant volumes of bulk commodities (Table 2). The patterns of trade in these centres are, however, quite different. Tauranga, New Plymouth, Christchurch, Nelson and the mineral sands terminal at Taharoa are net exporters of commodities, by weight, whereas Whangarei, Auckland and Invercargill import greater volumes of goods than they load (Table 3). These differences are best exemplified in the differences in trade at Whangarei and New Plymouth. Both ports are characterised by a large proportion of visits by bulk tankers, associated with major petrochemical facilities in each location. However, New Plymouth is a net exporter of products and Whangarei (Marsden Pt) a net importer (Table 3). Refined petroleum products from Whangarei are then transported by coastal tanker to other New Zealand ports.

Table 1. Risk factors associated with "propagule supply" and "site vulnerability" in ports and other major points of entry

Measure of propagule supply	**Indicator**
Quantity (number of propagules) per introduction event	*Ballast* Volume of ballast discharged *Hull fouling* Vessel size Vessel type Hull maintenance Time inactive in potential source ports
Frequency of introduction events	No. of international vessel visits Diversity or consistency of source ports Changes in shipping patterns
Duration of exposure	*Ballast* Flushing / exchange of port waters *Hull fouling* Time inactive in potential recipient ports
Viability of propagules	Environmental matching with source ports Transit time Transit route (hull fouling only)
Measure of site susceptibility	
Habitat availability	Range and area of natural habitats within or adjacent to the port Range and area of artificial habitats within or adjacent to the port
Physiological survival	Environmental matching with source ports

Forestry products have dominated recent bulk export growth in New Zealand. The volume of wood available for export is projected to increase by around 74% between 1996 and 2010. Forestry exports (logs, sawn timber and woodchips) account for more than 70% of the export tonnage from the Port of Tauranga, > 70% from Whangarei, 45% from Nelson, 32% from Napier, and 17% Bluff. Markets for these products are principally in Australia (31% by value), Japan (26%) and South Korea (11%) (Statistics New Zealand 1999). Christchurch is a major exporter of coal, with greater than half its overall volume of exports by weight (1.4 million tonnes) consisting of coal shipments.

An increasing number of passenger cruise liners is visiting New Zealand. In 1999, the reported ports of entry for these vessels reflected the distribution of New Zealand's major coastal tourist centres in the Bay of Islands (Opua), Auckland, Christchurch, Dunedin and Milford Sound (Table 2).

Large chartered and/or joint-venture fishing vessels arrived predominantly in Wellington and Nelson (Table 2). However, Timaru, Christchurch and Whangarei are also important domestic destinations for these vessels once they have entered the country. There was considerable interannual variation in the number of foreign vessels that arrived in New Zealand with almost twice as many arriving in 2000 than in 1999 (Fig. 2).

Table 2. International Vessel Arrivals to New Zealand Ports – 1999

	Vessel Type													
Port	Bulk	Chemical Tanker	Container	General Cargo	LPG tanker	Other	Passenger	Reefer	Roro	Tanker	Large Fishing	†Small Fishing	†Non-commercial craft	Total
Opua	0	0	0	0	0	0	6	0	0	0	0	0	-	6
Whangarei	32	0	0	12	0	6	0	5	1	44	2	6	134	242
Auckland	52	2	684	79	1	16	5	73	175	37	3	9	174	1310
Tauranga	88	0	63	35	0	0	1	20	0	10	0	7	19	243
Gisborne	14	0	0	0	0	0	0	11	0	0	0	0	0	25
Taharoa	9	1	0	0	0	0	0	0	0	1	0	0	0	11
New Plymouth	11	18	8	9	24	6	1	10	0	126	0	1	1	215
Napier	27	0	10	4	0	0	0	28	0	1	0	5	3	78
Wellington	8	0	15	4	0	2	1	0	10	11	17	9	37	114
Nelson	15	0	3	0	0	1	0	27	5	0	13	2	2	68
Picton	1	0	0	1	0	0	1	1	0	0	0	0	0	4
Westport	8	0	0	0	0	2	0	0	0	0	0	0	0	10
Christchurch	30	0	28	7	0	2	7	2	2	9	2	54	9	152
Timaru	3	0	0	5	0	0	0	5	0	0	0	0	0	13
Dunedin	7	0	21	3	0	0	4	0	0	0	0	0	1	36
Milford	0	0	0	0	0	0	2	0	0	0	0	0	0	2
Invercargill	25	0	37	18	0	1	1	3	0	1	0	1	0	87
Total	330	21	869	177	25	36	29	185	193	240	37	94	380	2616

†Provisional estimate from MAF quaratine database. Records nearest customs office.

Table 3 Volume of goods loaded and unloaded at each New Zealand port in 1999 and 2000.

	Gross weight loaded* (Tonnes)			Gross weight unloaded* (Tonnes)			Loaded – Unloaded (Tonnes)	
Port	1999	2000†	% change	1999	2000†	% change	1999	2000
Tauranga	5,325,753	6,205,974	16.5	1,022,074	1,198167	17.2	4,303,679	5,007,807
New Plymouth	3,779,829	3,678,437	-2.7	253,535	373,489	47.3	3,526,294	3,304,948
Auckland	2,251,331	2,097,011	-6.9	3,070,724	3,392,090	10.5	-819,393	-1,295,079
Christchurch (Lyttelton)	2,047,101	2,336,463	14.1	797,606	965,567	21.1	1,249,495	1,370,896
Napier	1,046,603	1,426,563	36.3	549,606	642,403	16.9	496,997	784,160
Nelson	925,968	1,110,780	20.0	59,936	96,079	60.3	866,032	1,014,701
Dunedin (Port Chalmers)	823,426	834,615	1.4	226,845	227,921	0.5	596,581	606,694
Taharoa	744,857	1,229,395	65.1	0	0	0	744,857	1,229,395
Whangarei	662,830	1,005,506	51.7	4,883,705	4,616,762	-5.5	-4,220,875	-3,611,256
Wellington	563,102	526,961	-6.4	686,268	840,708	22.5	-123,166	-313,747
Gisborne	514,148	544,388	5.9	8,151	280	-96.6	505,997	544,108
Invercargill (Bluff)	492,688	647,772	31.5	936,250	973,534	4.0	-443,562	-325,762
Timaru	106,083	141,586	33.5	151,032	180,101	19.2	-44,949	-38,515
Picton	76,295	71,120	-6.8	0	0	0	76,295	71,120
TOTAL SEAPORTS	19,500,176	21,907,118	12.3	12,645,733	13,507,110	6.8		

*Source: New Zealand Official Yearbook on the Web: 1999 (Statistics New Zealand)
†Provisional figures for 2000.

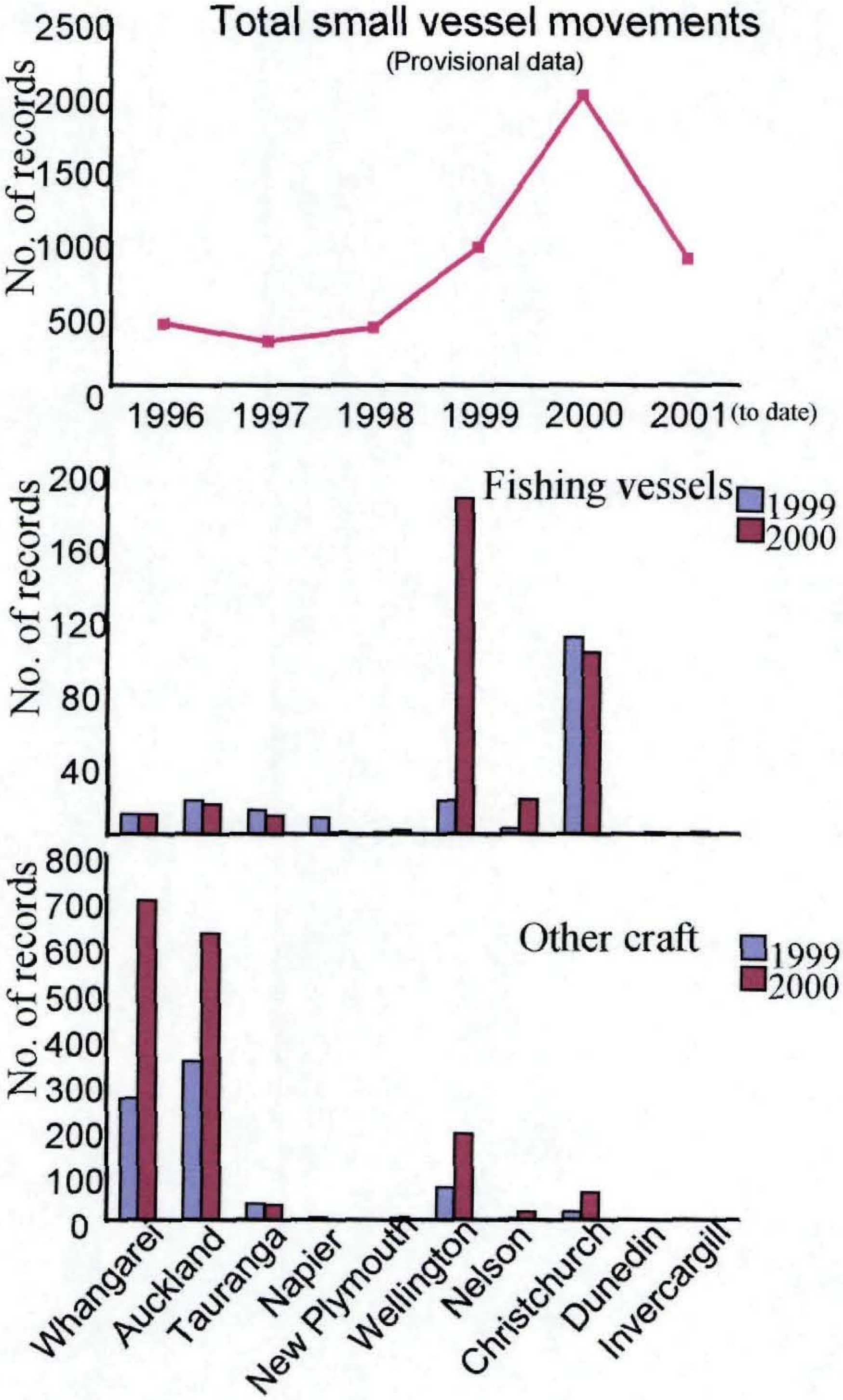


Figure 2. (Top) Estimated numbers of small vessels entering New Zealand waters between 1996 and 2001 and major points of entry for small fishing vessels (Middle) and private pleasure craft (Bottom). Data are from the NZ Quarantine Service database and are recorded by the nearest Customs Office, rather than by port.

5.4.2 Small craft arrivals

The number of small, unballasted craft entering New Zealand waters has increased markedly in the past four years. This category of vessels includes private pleasure motor launches, yachts and other sailing craft, and small fishing vessels (e.g. long-liners, line fishing and small seine vessels). Prior to 1999, fewer than 500 small vessels entered New Zealand each year (Fig. 2). Arrivals more than quadrupled in 2000, during the America's Cup defence, to around 2000 vessels. Preliminary data suggest a similarly large number of small vessels entered and/or departed New Zealand waters in the first half of 2001 (Fig. 2).

During 1999 and 2000, most international movements of small fishing vessels were recorded from Wellington and Christchurch (Fig. 2). Other small craft, predominantly yachts and motorised private pleasure craft, were recorded mostly in Whangarei and Auckland (Fig. 2). Small boat marinas in Whangarei, Opua (Bay of Islands) and Auckland are reportedly the major ports of entry for pleasure craft entering New Zealand waters (Quarantine Service, pers. comm.). Unlike most merchant vessels, chartered fishing boats and visiting pleasure craft are likely to spend considerable amounts of time in other domestic ports and coastal environments during their time in New Zealand. Identifying the risks that these vessels pose to particular locations requires better information on their patterns of movement and time at rest following their arrival in the country.

5.5 Volume of ballast discharged

The total amount of ballast discharged into a port depends upon a range of factors including the number type and size of arriving vessels, the weight and type of cargo that they are carrying on arrival, the depth of the port and state of the tide (Fig. 3). In general, the ballast component of a vessel's dead weight tonnage (DWT) both increases and becomes proportionately larger relative to the size of the ship in larger vessels (Hay et al. 1997). Bulk carriers tend to have fewer, but larger ballast tanks, and many use a cargo hold for 10, 000 to 15, 000 m^3 of sea water. A wood-chip carrier of 25, 000 tonnes may have just 10 tanks with a total capacity of 16, 000 m^3. A medium-sized container ship may have 20-24 tanks with a total ballast capacity of 8, 000 to 10,000 m^3 of water.

The total reported volumes of ballast discharged into New Zealand's ports are summarised in Figure 4. These data represent information available in the ballast water database at the time the report was prepared and are complete only for 1999. Despite some of the inadequacies of the data and database highlighted above (Section 3) and by Hay *et al.* (1997), the reported volumes appear to provide a reasonable indication of the relative risks on a port-by-port basis. To verify the relative accuracy of the reported volumes, I compared volumes of ballast discharged at each port to independent statistics on the difference in the volumes of exported and imported goods. Vessels that discharge the largest quantities of ballast are typically bulk carriers that arrive empty and depart fully laden (e.g. ships exporting iron sand, methanol or coal, Fig. 3). Bulk carriers that arrive in New Zealand fully laden and which leave empty discharge relatively small quantities of ballast, but are likely to take on significant volumes of water from New Zealand ports on departure (Hay *et al.* 1997). In general, the total volumes of ballast discharge reported in the database were in accordance with the net volume of goods exported from each port (Fig. 5). Therefore, simple trade statistics on the differences in volume of goods loaded and unloaded at each port provided a good predictor of the total volume of ballast discharged. Ports with the greatest net export surplus of goods by volume (e.g. New Plymouth, Lyttelton, Tauranga and Taharoa) received the greatest quantities of discharged ballast. Note that the relationship between net import volume and ballast discharge was also positive, since ports like Whangarei which have a substantial export deficit by volume are serviced by large bulk carriers which, despite being full on arrival, still carry larger volumes of ballast than many other vessel types. Whangarei is also a significant exporter of forestry products. A notable outlier in this relationship was the Port of Tauranga which, despite having the largest export surplus of all ports, received a substantially smaller than expected volume of discharged ballast. The reasons for this discrepancy are unclear, but it may be associated with under-reporting of ballast discharge or differences in the type of cargo being carried from the port. For example, bulk carriers exporting wood chips often discharge all their ballast, while ships exporting logs retain 8 – 10% of their ballast because the ship's centre of gravity is higher when logs are piled on the deck. Modern bulk wood chip carriers are also able to flood the main holds when they are empty, and it is unclear whether this form of ballast has been consistently reported.

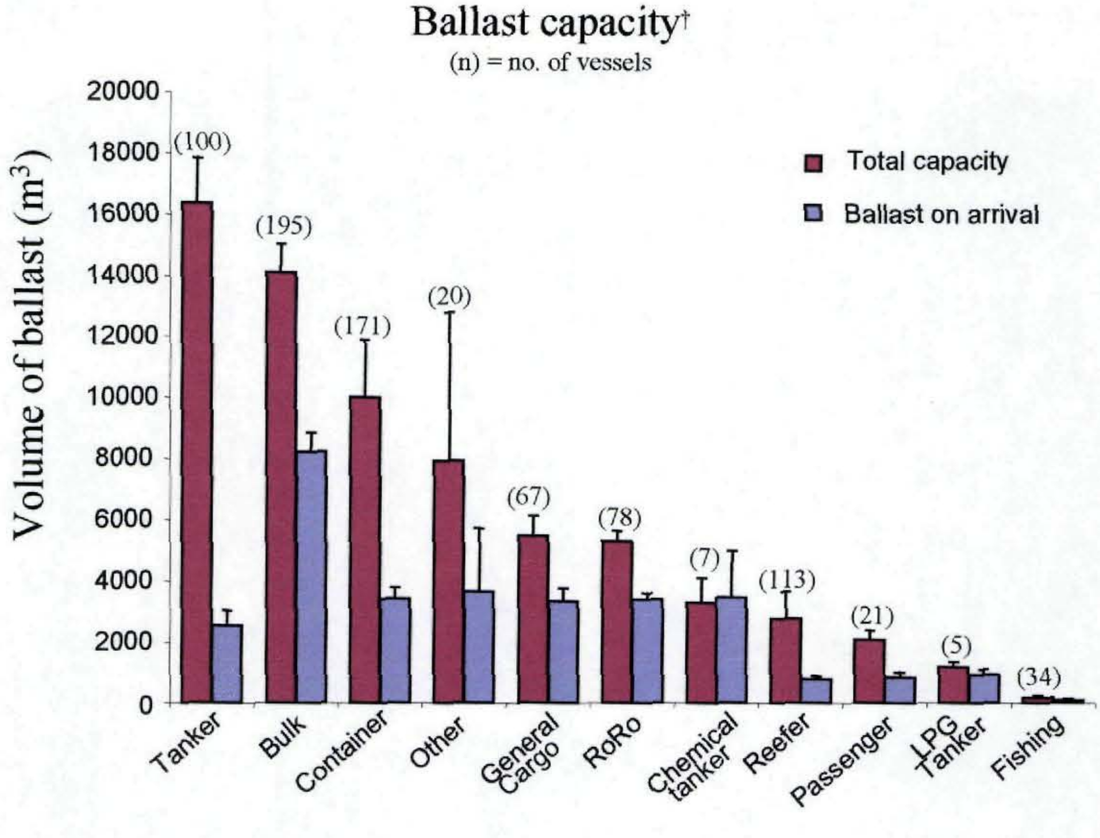


Figure 3. Reported mean ballast capacity of different types of vessels entering New Zealand and the actual volume of ballast carried on arrival.

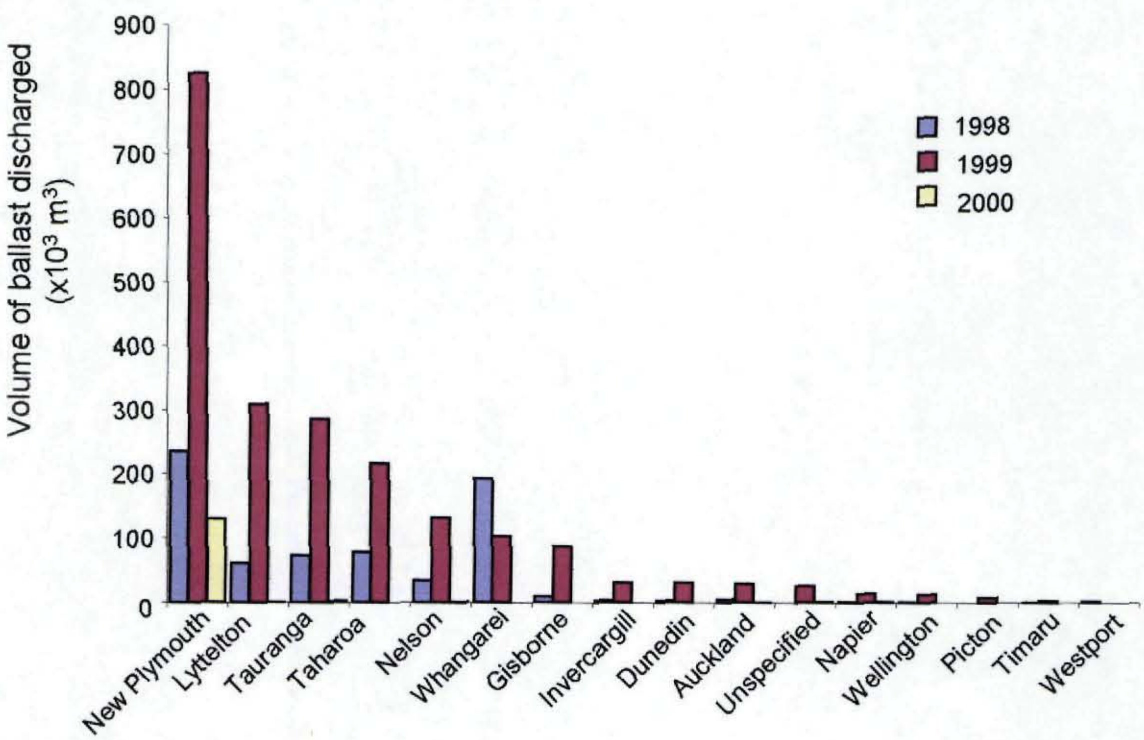


Figure 4. Total volume of ballast discharged in each New Zealand port. Data from the ballast database are complete only for 1999.

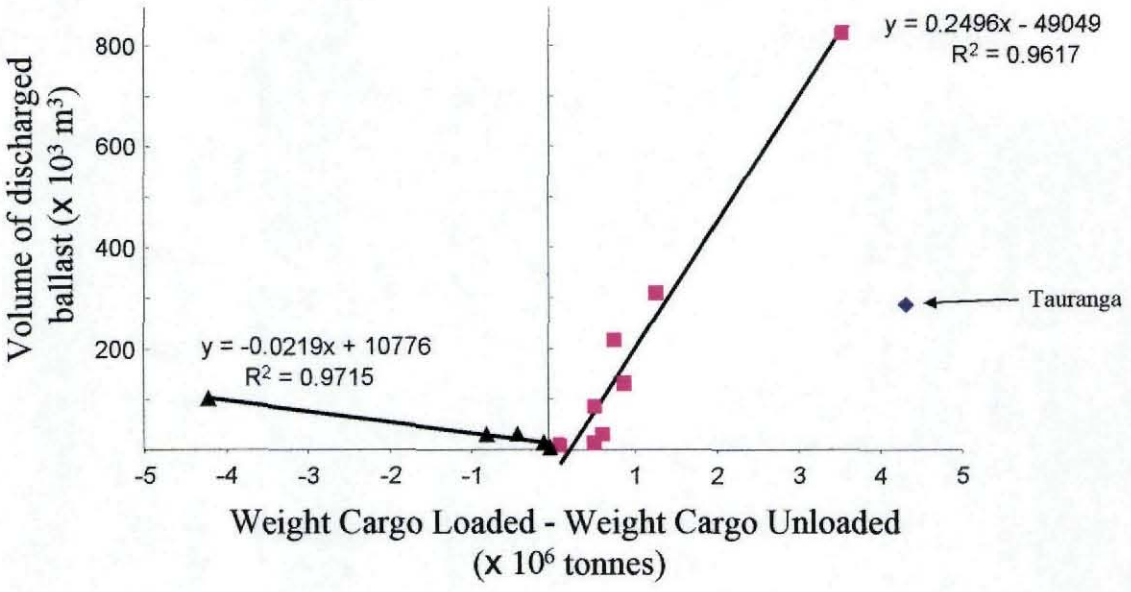


Figure 5. Relationship between gross statistics on the weight of cargo loaded and unloaded at each port and the reported volume of ballast discharged. Cargo data were obtained from Statistics New Zealand. Squares = ports that are net exporters of cargo, Triangles = ports that are net importers. The outlier (Tauranga) is indicated by a diamond.

5.6 Source ports

5.6.1 Volume of discharged ballast

Ballast water discharged into New Zealand ports was sourced from more than 23 different countries. Records in the ballast water database show Japan to be the greatest source of discharge, accounting for up to 31% of the identified volume of water discharged into New Zealand (Table 4). Most major ports received some discharge from Japan, but the greatest quantities were released at New Plymouth, Taharoa, Christchurch and Tauranga. Other major countries of origin for ballast included Australia, Hong Kong, China, South Korea and Taiwan. Southern Australia and, more recently, Japan, East Asia and the tropical Indo-Pacific are the most important sources for recent introductions of marine species to New Zealand (Cranfield *et al.* 1998). Ports that receive significant quantities of discharge from these regions, therefore, should be considered relatively high risk.

There is some uncertainty in data on source ports for ballast water. As much as 22% of the reported discharge in New Zealand ports was of unspecified origin and many of the port code entries in the ballast water database were inaccurately recorded. Where possible, tentative corrections were made to some of these entries by: (1) examining the predominant voyage routes of individual vessels, (2) cross-checking stated codes against likely ports in each country, and (3) by relating the vessel and cargo type to known operations at source ports. For example, vessels that reported their source port as 'AUKRN' were all tankers that arrived from Australia and discharged ballast at New Plymouth and Auckland. The port at which these vessels loaded was most likely the Australian oil refinery terminal at Kurnell ('AUKUR') in New South Wales. Around 412 entries were amended in this way, but their accuracy remains questionable. Source ports and countries could not be identified for a further 522 and 422 vessels (out of 2020 records), respectively. New Plymouth, Nelson, and Whangarei received the largest volumes of ballast from unspecified source countries (Table 4). Ballast from unspecified sources represented up to 48% of the total quantity discharged at New Plymouth. The volume of ballast discharged in each port from identified sources was not a useful predictor of the volume discharged from unspecified sources (linear regression, $r^2 = 0.352$), indicating that the unknown component of the database was not representative of verifiable data.

Table 4. Major sources of ballast water for each New Zealand port.

Port	Volume of Discharged Ballast by Country of Origin (m^3) Australia	China	Hong Kong	Japan	South Korea	Taiwan	Unspecified	Grand Total
Auckland	3656		1466	940	1353	3475	9681	20571
Christchurch	45396	15842	759	153376	25337	36073	77887	354670
Dunedin	2028			18697		7806	4834	33364
Gisborne	8890	3874		41469	7456	2594	30001	94284
Taharoa		49500		208080			37411	294991
Invercargill	7413	1714		7483	278		16207	33095
Napier	1243	790	313	3985			1810	8141
New Plymouth	507895	43220	210589	224601	20658	23681	119926	1150570
Nelson	3243	228		43099	858	9335	100238	157000
Picton	154			1618			5184	6956
Timaru	177				3012		696	3885
Tauranga	27477	14222	174	135850	80725	15850	61112	335410
Wellington	3117		348	7371	763		2937	14536
Whangarei	5038	1958	17638	66087	26218	8384	169333	294656
Westport	2116							2116
Unspecified	20658			444	606		20853	27675
Grand Total	**638500**	**131348**	**231286**	**913100**	**167264**	**107198**	**658110**	**2846806**

5.6.2 Diversity/fidelity of source ports

Ballast discharged in Auckland was sourced from at least 15 different countries (Fig. 6). In total, Auckland has links to more than 160 different ports in 73 countries (http://www.poal.co.nz/index.htm). New Plymouth, Tauranga, Christchurch, and Nelson also received discharge from a diverse range of source countries and ports, although the total quantities of ballast were substantially larger than was discharged in Auckland. The Taharoa Terminal was notable in that it received very large quantities of ballast from relatively few identified source ports and countries (Fig. 6). These were located predominantly in China and Japan (Table 4).

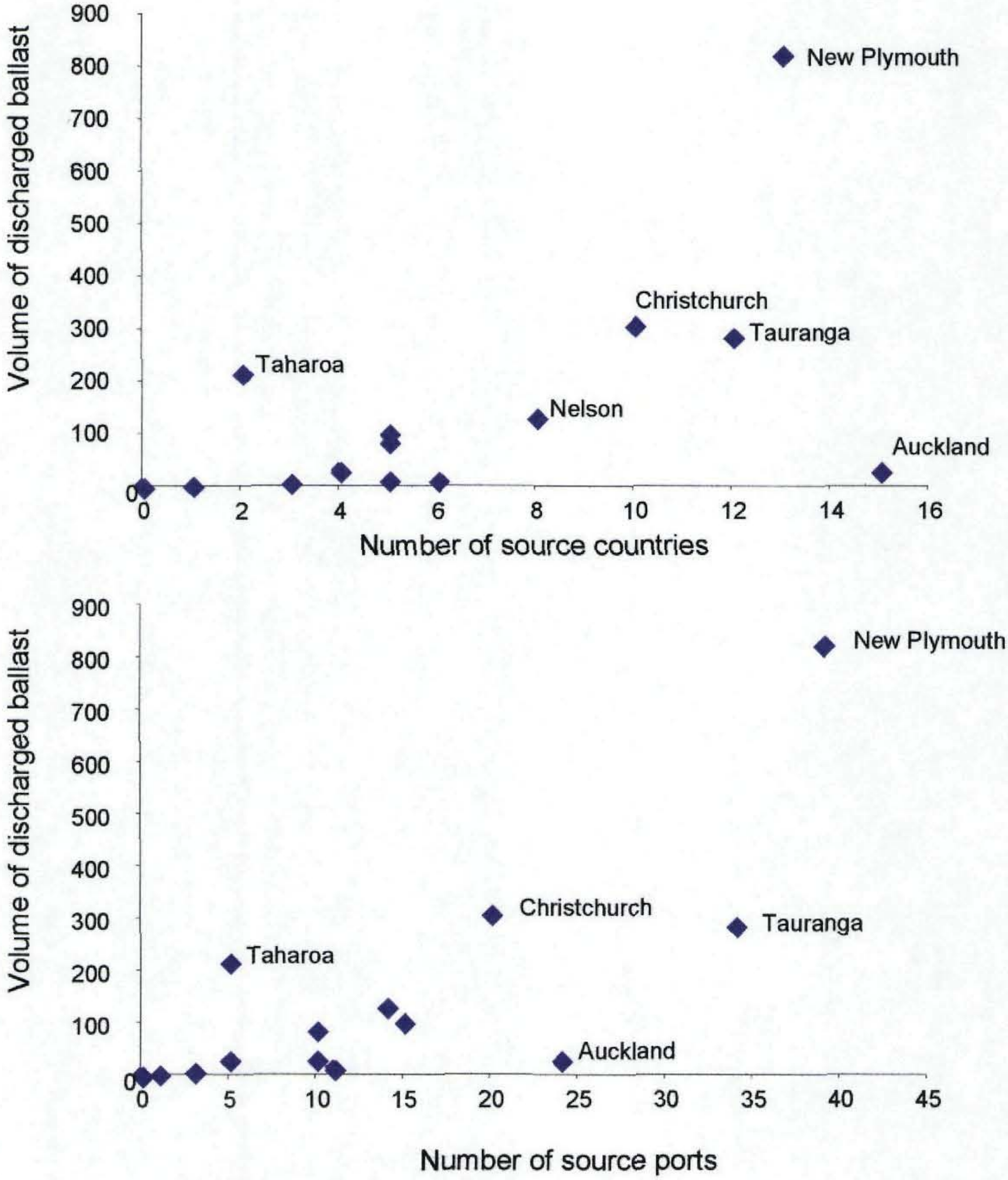


Figure 6. Relationships between the number of different source countries (Top) and ports (Bottom) and the total volume of ballast discharged in each port.

5.6.3 Changes in shipping patterns

The servicing of ports by international shipping lines is dynamic, with services being established or discontinued as markets develop and as commercial decisions by individual port companies provide incentives for direct international links. Changes in the pattern of shipping expose the port to species that it may not have been been exposed to, and have been linked with the appearance of NIS in new areas (Carlton 1996). Several notable changes in the servicing of New Zealand ports have recently been announced. Port Taranaki has recently announced a new direct container service to North America and Latin America. Vessels in this line will enter New Zealand via either Auckland or Tauranga from the US west coast, after having visited ports in Philadelphia, the Bahamas, and Panama. South Port in Bluff has established a new service that links it directly with Japan, Korea and Northern China. This direct link is predominately for the export of forestry products and is likely to involve visits by empty bulk carriers. In Christchurch, a new direct line has been established for bulk commodity export to Taiwan.

5.6.4 High risk source ports

The Ministry of Fisheries identified Port Phillip Bay in Victoria, Australia and all ports in Tasmania, Australia as particularly high risk source locations for ballast water arriving in New Zealand. This is because of the relatively short transit times to New Zealand and the large number of invasive species present within these regions that have not yet established in New Zealand. At least 307 vessels listed their last port of call as Port Phillip Bay or Tasmania. Most (n = 225) had come directly from the Port of Melbourne to Auckland (n = 112 entries), Bluff (50 entries), New Plymouth (20 entries) or Christchurch (19 entries). Vessels that departed from Tasmania (50 entries) went mostly to Bluff (18 entries), Christchurch (5 entries) and New Plymouth (4 entries).

Question 2 (Part 1) on the ballast reporting form requires masters to specify if the vessel under their control loaded ballast in either Port Phillip Bay or Tasmania. Ninety eight percent of entries in the database answered this question, but only 91 vessels had ballasted in one or more of the high risk locations. The majority of these listed their port of arrival as Auckland (n = 41), Bluff (n = 14), or Tauranga (n = 11).

5.7 Hull fouling

5.7.1 Quantity of fouling

A preliminary survey of hull fouling on international vessels was undertaken by NIWA in 1999 (James and Hayden 2000). Twelve merchant vessels, including bulk carriers, container vessels and a passenger liner (> 500 tonnes), were surveyed in Centreport, Wellington Harbour. A further 27 international yachts moored in Gulf Harbour Marina (Auckland) for the America's Cup were also examined. The survey showed that, on average, the relative cover and diversity of living organisms tended to be greater on hulls of the yachts (mean = 42% cover) than on merchant vessels (mean = 15% cover). Fouling on merchant vessels was concentrated mainly in recesses on the under-surfaces of the boats where cleaning and antifouling is difficult. Recreational vessels tend to have slower sailing speeds, use less toxic antifoulants and have more variable maintenance schedules than larger commercial vessels which may allow greater survival of attached organisms (Coutts 1999). Other high risk category of vessels appear to be chartered fishing boats, some of which are known to have arrived in New Zealand with a substantial biomass of non-indigenous fouling organisms (Hay and Dodgshun 1997). The New Zealand Fishing Industry has recently adopted a voluntary Code of Practice on hull-fouling to address this problem (Phahlert 1997). Fishing vessels are requested to have their hulls checked prior to entering the New Zealand EEZ. Where this has not been done, a hull inspection may be undertaken on arrival and the vessel required to be cleaned before departing for fishing grounds.

5.7.2 Time inactive in source ports

Non-commercial pleasure craft and seasonal fishing boats are likely to spend the longest periods of time at rest. Before coming to New Zealand, fishing vessels may be tied up for long periods of time in foreign ports where they can accumulate a considerable assemblage of fouling organisms on their hulls. Question 7 in the ballast reporting form asked masters to indicate if their vessel had been laid-up (inactive) for ≥ 3 months prior to leaving for New Zealand. Six vessels answered this question affirmatively. All six were fishing boats. At the time that the report was prepared no data were available on the average periods of residence of international pleasure craft in New Zealand marinas. Unpublished data on pleasure craft in North Queensland suggest a bimodal patterns of residence by visiting boats in which marinas are usually visited for a period of < 2 weeks, but some locations are used as a base for longer visits, of up to 8 months (Floerl and Inglis, unpubl. data).

5.7.3 Maintenance schedules

Figure 7 shows the frequency distribution of reported times since vessels in the ballast database were last dry-docked and cleaned. Most of the merchant vessels entering New Zealand were well within manufacturer's recommendations for the maximum in-service period of Controlled Depletion Polymer (CDP), Self-Polishing Co-polymer (SPC) and Biocide Free Fouling (BFF) antifoulant paints, the main types of fouling systems for merchant vessels (International Marine Coatings1999). International Marine Coatings, one of the largest manufacturers of antifoulant coatings, estimates paint performance of between 60-78% (based on the type, severity and extent of fouling) for up to 36 months of use of CDP antifoulants, and 70-96% performance of SPC and BFF coatings for up to 60 months use (International Marine Coatings 1999). The average in-service period for most vessel types in the ballast database was around 18 months, with the longest time between dry-docking reported by LPG tankers (Fig. 8). Entries in the database are not independent, however, as the 35 recorded visits by LPG tankers into New Zealand were made by just 7 vessels. All but one entered New Zealand in New Plymouth. This is significant because a previous study of an Australian LPG tanker impounded in New Plymouth in 1998 found an exceptional cover (> 11 $kg.m^{-2}$) of fouling organisms on its hull that consisted almost exclusively of exotic species (James and Hayden 2000).

Only limited information is available on the maintenance schedules of small craft arriving in New Zealand. All but one of the international yachts surveyed in Gulf Harbour Marina during the America's Cup had been antifouled in the preceding 24 months. However, the sample is unlikely to be representative of most arrivals of this vessel type. Private pleasure craft surveyed in marinas in northern Queensland had an average between-service period of about 22 months (670 days) with large variation among individual craft (Floerl and Inglis unpubl. data).

Forty entries in the ballast database indicated that they would be cleaning the hull of their vessel while in New Zealand. These were mostly container carriers (n = 14) and fishing vessels (n = 12), but also included bulk carriers (n = 4), general cargo carriers (n = 3), passenger liners (n = 3), reefers (n = 6), RoRo's (n = 2), a tanker, and one unspecified vessel. The ports where the boats were to be serviced were: Auckland (n = 15), Wellington (n = 9), Nelson (5 – all fishing boats), Christchurch (n = 4), Tauranga (n = 4), Whangarei (n = 4), Dunedin (n = 1), and Napier (n = 1)[1].

5.7.4 Time in New Zealand waters

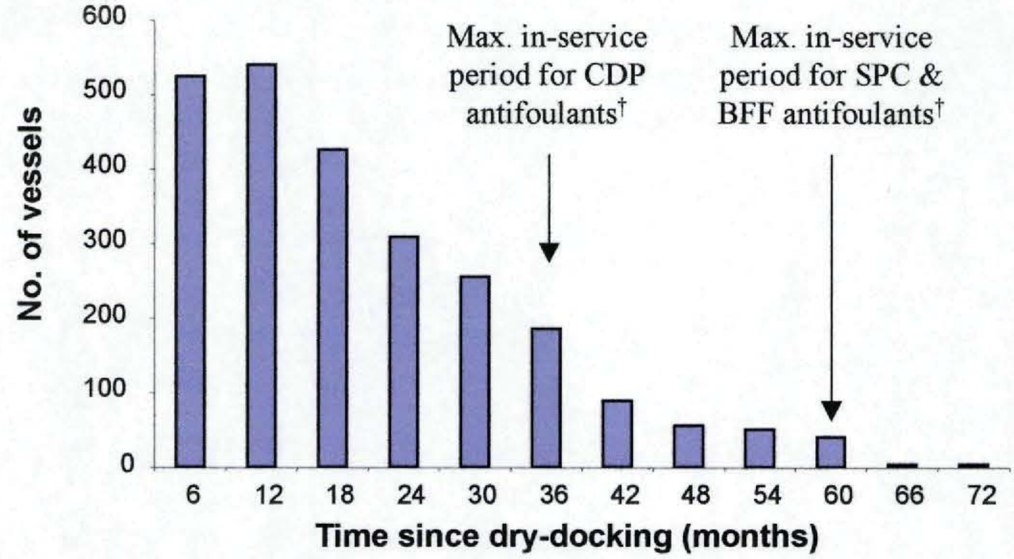
Most of the large, ballasted vessels spent an average of less than six days in New Zealand waters before departing overseas (Fig. 8). Fishing vessels stayed for the longest period of time (mean = 24 days, max. 115 days; Fig. 8). However, a large proportion of this time is likely to have been spent at sea. Fishing vessels were also more likely than other vessels (38%) to not specify a date of departure from New Zealand on the reporting form. No data were available on the average length of stay by small craft in New Zealand, but visits by these craft are likely to be of comparatively long duration (weeks-to-months).

5.8 Characteristics of the ports

5.8.1 Variety and extent of habitat available

The physiography of New Zealand ports is highly variable. Nine of the ports are located in natural deep water harbours or embayments that provide sheltered waters for berthage and which have a range of surrounding habitats that may be colonised by NIS (Table 5). Others are situated in small river estuaries (e.g. Gisborne, Nelson), or have been constructed on exposed shorelines, with protection from

[1] There were 3 blank entries



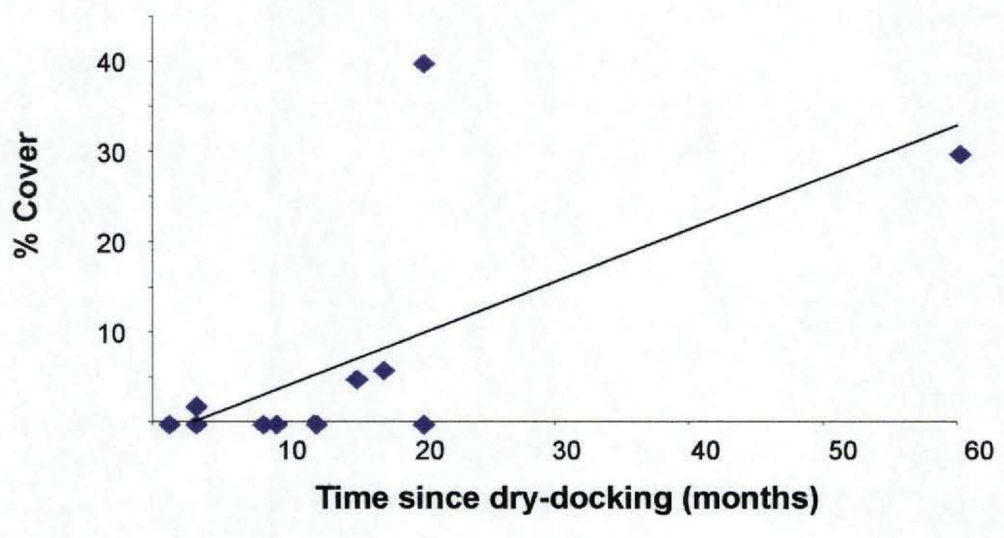


Figure 7. (Top) Distribution of the in-service period of antifoulants on ballasted vessels entering New Zealand waters. Arrows denote the maximum recommended in-service periods for CDP, BFF and SPC antifoulants.

(Bottom) Estimated percentage cover of fouling organisms on the hulls of 12 merchant vessels surveyed by NIWA in 1999 (Source: James and Hayden 2000).

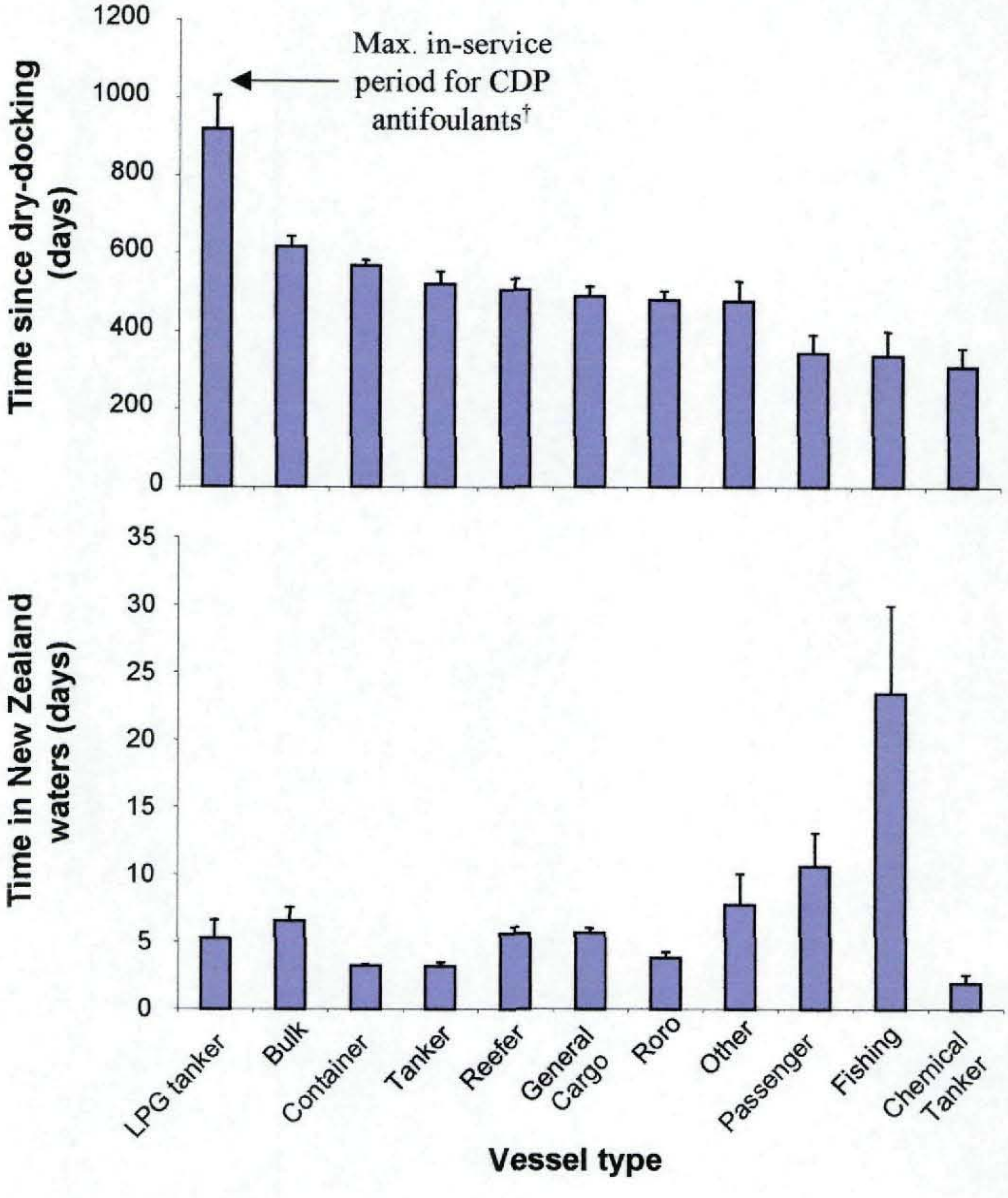


Figure 8. Average (+s.d.) in-service period (Top) and duration of visit to New Zealand (Bottom) of different vessel types.

Table 5. General descriptions of the port location and surrounding environment

Port	Physical location: Large natural embayment or harbour	River mouth / estuary	Open coast	Offshore terminal	Description
Opua	✓ (Waikare Inlet, Bay of Islands)				Small domestic shipping wharf and marina
Whangarei	✓ (Whangarei Harbour)				Separate terminals at Marsden Pt, Portland, Port Whangarei and Whangarei Basin Marina
Auckland	✓ (Waitemata Harbour)				Multiple terminals located in central Auckland. Two marinas are associated with the port (Viaduct Basin and Westhaven Marina) and a number of other large marinas are distributed in the Auckland region, notably Gulf Harbour Marina (Whangaparoa)
Tauranga	✓ (Tauranga Harbour)				25 berths and associated cargo terminals situated at the entrance to Tauranga Harbour. Associated boat marina
Gisborne		✓			Situated at the entrance to the Turanganui River
Taharoa				✓	Terminal for mineral sands located off the Kawhia coast
New Plymouth			✓		Constructed harbour. Artificial breakwalls enclose the port and a popular beach.
Napier			✓		Constructed harbour surrounded by artificial breakwalls. Adjacent to Ahuriri Estuary.
Wellington	✓ (Port Nicholson)				Main port located in central Wellington. Separate oil terminals at Burnham and Seaview.
Nelson		✓			Dredged harbour contained between Boulder Bank and the mainland, bounded to the SW by Haulashore Island and on the NE by the mudflats of Nelson Haven
Picton	✓ (Queen Charlotte Sound)				Small, domestic terminal located at the head of Queen Charlotte Sound. Separate forestry terminal in Port Shakespeare. Boat marinas in Picton and Waikawa.
Westport		✓			Small port located within the Buller River mouth

Port	Physical location: Large natural embayment or harbour	River mouth / estuary	Open coast	Offshore terminal	Description
Christchurch	✓ (Lyttelton Harbour)				Multiple terminals centrally located in Lyttelton Harbour, enclosed by an artificial breakwall.
Timaru			✓		Constructed harbour surrounded by artificial breakwalls.
Dunedin	✓				Separate terminals located throughout the harbour at Port Chalmers, George Street, Beach Street, Dunedin City and Ravensbourne
Milford	✓ (Milford Sound)				Small port at the head of Milford Sound, predominantly servicing tourist vessels
Invercargill	✓ (Bluff Harbour)				Multiple terminals situated 2 miles inside Bluff Harbour

artificial breakwalls (e.g. Timaru, Taranaki). Ports in large sheltered embayments and estuaries that have restricted exchange of water with open coast environments are likely to have a wide range of habitats available and, because of the limited dilution of arriving propagules, may be at greatest risk of incursion (Ruiz *et al.* 2000, Floerl & Inglis in review).

5.8.2 Changes in the availability of habitat

Changes in the availability of habitats for NIS can occur through natural events, such as storms, which remove or reduce the abundance of native species, or as a result of human alteration of the environment. Construction and reclamation activities at ports can make new areas of artificial habitats available for colonisation by NIS.

Construction of new fishing and main wharves is currently underway in Nelson. Port Marlborough established a new export wharf for forestry products in 2000 in Shakespeare Bay, Marlborough Sounds. The Cawthron Institute is currently undertaking monitoring of exotic species at this site. The most significant alteration to existing port infrastructure in New Zealand is currently a joint venture between Port of Tauranga and Northland Port to relocate Port Whangarei from within the Whangarei Harbour basin to Marsden Point, and associated construction of a major forestry terminal in partnership with Carter-Holt Harvey. Construction of the new port is well underway. It is expected to be commissioned early in 2002.

6 Risk profiles

The range of indicators described above provides an illustration of the complex and diverse influences on the likelihood of establishment by NIS in any particular port. Few of these indicators have been tested directly, and it is likely that no single indicator will provide a robust measure of the likelihood of establishment by exotic species (Carlton 1985, 1996, Ruiz *et al.* 2000). For example, Ruiz *et al.* (2000) showed that the distribution of invasive marine NIS in the USA was not well correlated with the number of international ship arrivals or volume of discharged ballast.

The most efficient way to understand variation in the risk of incursion is to select sites for surveillance that have contrasting risk profiles, based on multiple indicators of risk. The baseline assessment and subsequent surveillance can then be developed in an adaptive way (sensu Walters and Holling 1990) to test which combinations of the risk factors best explain the existing distribution of NIS in New Zealand's international points of entry. There are, however, no existing precedents for combining multiple indicators of incursion risk to give a realistic representation of relative and actual likelihood of establishment by NIS at individual locations.

To develop preliminary risk classes for New Zealand's ports, I used multivariate statistical techniques to provide objective, contrasting risk classifications of the different ports. The analyses used six quantitative variables for each port that were derived from the indicators described above. These were the:

- total number of visits per annum by international merchant vessels
- total number of visits per annum by international fishing vessels
- total number of visits per annum by international pleasure craft
- total number of ballast discharge events per annum
- total volume of ballast discharged per annum, and
- total number of source ports of arriving vessels.

The six variables were selected because they:

(a) capture most of the identified indicators of propagule pressure,
(b) represent different classes of risk (e.g. ballast discharge vs hull fouling),
(c) integrate several indicators (e.g. no. of source ports is correlated with no. of source countries), and
(d) were able to be quantified from available data.

For example, fishing vessels and pleasure craft exhibit very different activity patterns from merchant vessels. They visit different ports, spend more time laid-up in New Zealand and offshore, have slower steaming speeds and are more likely to be a vector for hull fouling organisms than for ballast water arrivals. Other, combinations of variables (e.g. total visits x number of discharge events x no. of source ports) provide a measure of the likely diversity and/or frequency of transmission of propagules from different geographic areas.

6.1 Statistical Methods

Raw data on the six variables were summarised for each port from the ballast water and Quarantine Service databases. Because it was not possible to attribute small craft numbers to particular marinas, all analyses were done using combined port and small boat marina statistics (i.e. "harbours"). Also, because data on small craft arrivals in Opua were not distinguished from those in Whangarei (the nearest customs centre), I assumed that boats arrived in equal numbers at these two destinations. Violation of this assumption is unlikely to have a major impact on the final risk profiles (see results below).

The variables were standardised to z-scores to give equal weight to each measure of risk. Hierarchical cluster analysis, using a Euclidean distance metric and single linkage, was used to calculate groupings of ports with similar risk profiles. A Principal Components Analysis (PCA) was used to reduce variation among the ports in the six variables to two factors that explained 78% of the variation in the data. PCA biplots[2] provided a graphical representation of the different profiles represented by these two multivariate factors.

[2] PCA biplots are an ordination technique in which the locations of samples (in this case the ports) are represented in 2 (or more) dimensional space relative to derived axes that explain most of the variation in the data. Vectors overlaid on the plot indicate the strength (length of the vector) and direction of association between each variable and the derived axes.

6.2 Results

Results of the two analyses are presented in Figure 9. Four major ports – Auckland, New Plymouth, Christchurch and Tauranga – separate out in the cluster analysis as having distinctly different risk profiles from the other 13 locations that were considered. Auckland is distinguished by having a very large numbers of visits by merchant vessels and pleasure craft, vessels arriving from a large number of source countries, and comparatively small volumes of discharged ballast (Fig 9). In contrast, New Plymouth receives very few pleasure craft, but receives large quantities of ballast discharge, from a range of source countries. Christchurch and Tauranga both receive moderate-to-large numbers of merchant vessels, few pleasure craft and comparatively moderate-to-large volumes of ballast discharge. The PCA biplot depicts four generic risk classes that are represented by the four corners of the plot. Descriptors of the risk classes in each quadrant are provided in the boxes.
The four classes were ports with:

- Large numbers of merchant vessels, large numbers of pleasure craft, large numbers of source countries, a small number of ballast discharge events, and which received a small volume of discharged ballast.
- Moderate numbers of merchant vessels, moderate numbers of pleasure craft, small numbers of source countries, a small number of ballast discharge events, and which received a small volume of discharged ballast.
- Small numbers of pleasure craft, large numbers of source countries, a large number of ballast discharge events, and which received a large volume of discharged ballast.
- Small numbers of merchant vessels, small numbers of pleasure craft, small numbers of source countries, a moderate number of ballast discharge events, and which received a moderate volume of discharged ballast.

The strength of association of each port with each class is represented by its location relative to the corners of the plot. As a general rule, ports located toward the periphery of the plot (particularly Auckland and New Plymouth) are the most distinctive and are likely to constitute the greatest risk.

7 Sampling and resource criteria

A range of other sampling and resource considerations will also determine the priority and timing of surveys in the different ports.

7.1 Geographic coverage

The likelihood of detecting an incursion is a function of the number of sites included within the surveillance network. Because of the uncertainty in predicting where any new incursions will occur, a surveillance network that includes ports from different biogeographic regions throughout the country will provide the greatest chance of detection.

7.2 Access and Occupational Health & Safety (OSH) considerations

The success of this project depends upon the ability of field teams to access commercial shipping terminals. The cooperation of the port companies and harbour masters is essential to ensure that the work is carried out efficiently and safely without risk of harm to commercial operations or NIWA personnel and equipment. The selection of ports for surveillance will ultimately depend upon the willingness of port operators to liase with NIWA field staff implementing the surveys.

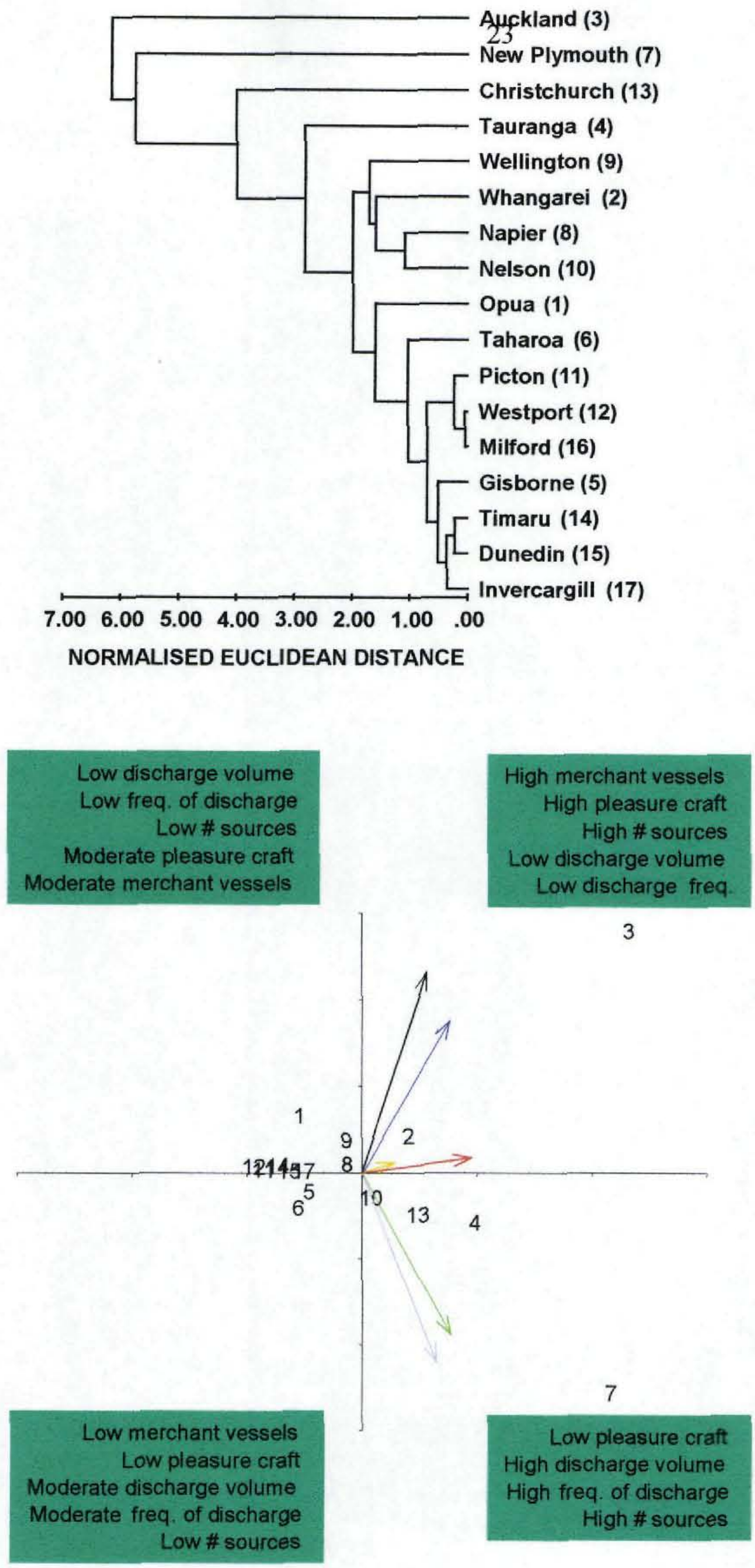


Figure 9. (Top) Cluster analysis of ports based on the 6 measures of risk. (Bottom) PCA biplot of the risk classes of different ports. Numerical codes for the ports are indicated in the figure above. Arrows represent the relative weightings on each axis of each of the six descriptor variables (black = # pleasure craft, blue = # merchant vessels, yellow = # fishing vessels, red = # source ports, green = volume of discharge, lavender = # discharge events). The length of each arrow indicates the correlation of each variable with the factor axes. The boxes indicate the risk profile in each quadrant of the plot.

7.3 Feasibility and cost

The isolation and environmental conditions at some ports can make them hazardous or costly to sample using the established CRIMP protocols. In most instances, surveys will be possible in the New Zealand ports with only minor modifications of the CRIMP protocols (e.g. substitution of remote collection methods such as netting & trapping where visual surveys are not possible). However, the deep water, open coast situation of the Taharoa terminal makes it extremely difficult to sample and will require quite different survey techniques. It will be particularly expensive to survey. Inclusion of this port in the current programme of port surveys will detract from the broad geographic coverage of coastal ports by consuming a disproportionate amount of the available resources . Consideration should be given to funding surveys at this location under a different contract so that appropriate survey protocols and costings can be determined.

7.4 Complementarity with ZBS2000/01

Complementarity of site selection with MFish project ZBS2000/01 will create greater efficiencies in training, field and laboratory costs. There is considerable potential to increase the consistency and quality of information retrieved and lower the costs involved if these two projects are integrated effectively. Importantly, where there is suitable habitat nearby, propagules of NIS may not establish founder populations within the immediate confines of the port environment. This is most likely in ports that are located within large harbours, estuaries or sheltered embayments, particularly where the port itself is dispersed over several terminals within the harbour (e.g. Whangarei, Wellington, and Dunedin). In these situations it is important that sampling within, and outside the port area be coordinated.

8 Recommendations

NIWA's intention is to use baseline surveys of the ports to test the risk characterisation described above so that future surveillance work can be developed adaptively and refined according to the areas of greatest risk. Below, we have recommended an initial list of 17 points of entry to be surveyed over the next two years. These constitute ports that are considered both relatively high- and moderate risk points of entry under the classification scheme. Nine ports will be surveyed in 2001-2002. The order of survey does not necessarily reflect the level of risk. For example, NIWA is planning to have separate field teams conduct the surveys in the North and South Islands. The order of the surveys, therefore, also incorporates field logistics by endeavouring to cover clusters of ports in the same geographic region within the same schedule of field trips. Because of its central location, we anticipate that the first survey will be done at Centre Port in Wellington (a moderate risk port). This will provide an opportunity to train the field teams and laboratory teams at one central location.

Surveys of Port of Northland (a relatively high risk port) are recommended for 2002-2003 because of the current relocation of Port Whangarei to Marsden Point. Baseline surveys for future incursions at this port are most appropriate at the site of likely future port operations, rather than at the existing terminals.

Information used to develop the risk profiles in this report was based on available data on patterns of international ship traffic. The Port of Onehunga was not included in the analysis, but perhaps should be considered by MFish in the final selection of locations because of its importance as a domestic hub-port and its location in Manukau Harbour, a regionally significant estuary. Similarly, information on the arrival and movements of pleasure craft and fishing vessels was only available at a relatively coarse geographic level. Prior to the surveys, NIWA will seek additional information from marina operators in high risk points of entry (e.g. Bay of Islands, Whangarei, Auckland) to identify marinas that lease the greatest numbers of berths to international vessels.

8.1 Proposed Schedule of surveys

2001-2002
Wellington
Auckland Port
Auckland Marina
Port of Tauranga
Port of Taranaki
Port of Lyttelton
Port of Nelson
Port of Picton
Port of Westport

2002-2003
Port & Marina of Opua
Port of Northland
Whangarei marina
Port of Gisborne
Port of Napier
Port of Timaru
Port Otago
South Port (Bluff)

9 Acknowledgements

Several other NIWA staff made valuable contributions to this report. Katie Image helped construct maps, Martin Unwin applied his deft touch to cleaning up the ballast database, and Barbara Hayden and Nick Gust provided useful discussions on the content of the report.

10 Literature cited

Carlton, J. T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanogr. Mar. Biol. Ann. Rev.* 23: 313-71.

Carlton, J. T. 1996. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78: 97-106.

Coutts, A.D.M. 1999. Hull fouling as a modern vector for marine biological invasions: investigation of merchant vessels visiting northern Tasmania. M.App.Sci. Thesis, Australian Maritime College, Tasmania, 283 pp.

Cranfield, H. J.; Gordon, D. P.; Willan, R. C.; Marshall, B. A.; Battershill, C. N.; Francis, M. P.; Nelson, W. A.; Glasby, C. J.; Read, G. B. 1998. Adventive marine species in New Zealand. NIWA Technical Report 34. Wellington. 48 p.

Culver, C. S.; Kuris A.M. 2000. The apparent eradication of a locally established introduced marine pest. *Biological Invasions* 2: 245-53.

Field, D. 1999. Disaster averted? Black striped mussel outbreak in northern Australia. *Fish Farming International* 26: 30-31.

Floerl, O.; Inglis, G.J. in review. Increased propagule pressure of fouling organisms in enclosed boat harbours: implications for the spread of non-indigenous species. Manuscript submitted to *Marine Ecology Progress Series.*

Forsyth, D.M.; Duncan, R.P. 2001. Propagule size and the relative success of exotic ungulate and bird introductions to New Zealand. *American Naturalist* 157:583-595

Foster, B. A.; Willan, R. C. 1979. Foreign barnacles transported to New Zealand on an oil platform. *New Zealand Journal of Marine and Freshwater Research* 13: 143-49.

Global Ballast Water Management Programme 2001. Port surveys underway. *Ballast Water News* 4: 3-5.

Grosholz, E. D.; Ruiz, G. M. 1996. Predicting the impact of introduced marine species: lessons from the multiple invasions of the European green crab *Carcinus maenas*. *Biological Conservation* 78: 59-66.

Hay C.; Dodgshun, T. 1997. Ecosystem transplant? The case of the Yefim Gorbenko. *Seafood New Zealand.* 13-14.

Hay, C.; Handley, S.; Dodgshun, T. Taylor, M., Gibbs, W. 1997. Cawthron's Ballast Water Research Programme: Final Report 1996-1997. Cawthron Report No. 417, Cawthron Institute, Nelson, New Zealand. 144 p.

Hewitt, C. L.; Martin, R. B. 2001. Revised protocols for baseline surveys for introduced marine species: survey design, sampling protocols and specimen handling. Technical Report Number 22. Centre for Research on Introduced Marine Pests, CSIRO, Hobart, Tasmania. 46 p.

Inglis, G.J. 2001. Criteria for identifying and selecting high value locations and locations at risk of invasion by exotic marine organisms in New Zealand. Draft Research Report for Ministry of Fisheries Project ZBS2000/01, Objectives 1 & 2. NIWA Client Report, Christchurch. 42 p.

International Marine Coatings, 1999. Antifoulings and fouling control systems. Pages Azko Nobel, Houston, TX.

James, P.; Hayden, B. 2000. The potential for the introduction of exotic species by vessel hull fouling: a preliminary study. NIWA Client Report No: WLG 00/51. Wellington. 16 pp.

Kolar, C. S.; Lodge, D. M. 2001. Progress in invasion biology: predicting invaders. *Trends in Ecology and Evolution* 16: 199-204.

Lonsdale, W.M. 1999. Global patterns of plant invasions and the concept of invasibility. *Ecology.* 80: 1522-1536.

Mack, R. N.; Simberloff, D.; Lonsdale, W. M.; Evans, H.; Clout M.; Bazzaz F.A. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications* 10: 689-710.

Moody, M. E.; Mack, R. N. 1988. Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology* 25: 1009-1021.

Nichols, F. H.; Thompson, J. K.; Schemel, L. E. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian Clam *Potamocorbula amurensis*. II. Displacement of a former community. *Marine Ecology Progress Series* 66: 95-101.

Pfahlert, J. 1997. Avoiding hull contamination of the New Zealand environment by fishing boats. *Seafood New Zealand* 5 (May): 15.

Ruiz G.M.; Carlton J.T.; Grosholz E.D.; Hines A.H. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent, and consequences. *American Zoologist* 37: 621-32.

Ruiz, G. M.; Fofonoff, P.; Hines, A. H.; Grosholz, E. D. 1999. Non-indigenous species as stressors in estuarine and marine communities: assessing invasion impacts and interactions. *Limnology and Oceanography* 44: 950-72.

Ruiz, G. M.; Fofonoff, P. W.; Carlton, J. T.; Wonham, M. J.; Hines, A. H. 2000. Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. *Annual Reviews in Ecology and Systematics* 31: 481-531.

Stachowicz, J. J.; Whitlach, R. B.; Osman, R. W. 1999. Species diversity and invasion resistance in a marine ecosystem. *Science* 286: 1577-79.

Stanton, B. 1997. The likelihood of transfer of marine organisms by ocean currents in the New Zealand region. NIWA Client Report No: WLG 00/51, 15 pp.

Statistics New Zealand, 1999. New Zealand Official Yearbook on the Web (1999). http://www.stats.govt.nz/domino/external/PASfull/PASfull.nsf/Web/Yearbook+New+Zealand+Official+Yearbook+On+The+Web+1999?OpenDocument.

Veltman C.J.; Nee, S; Crawley, M.J. 1996. Correlates of introduction success in exotic New Zealand birds. *American Naturalist* 147:542-557

Walters, C. J.; Holling, C. S. 1990. Large-scale management experiments and learning by doing. *Ecology* 71: 2060-2068.