New Zealand marine biosecurity research directions to underpin management

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Introduction

Since the Rio Convention, human-mediated activities leading to species loss have become central concerns, leading to significant effort to prevent, ameliorate, and mitigate impacts. One leading factor is the transport and establishment of non-native species in regions and communities where they did not evolve. Such biological introductions appear to be increasing globally (Carlton 1989, 2001; Hewitt 2003), largely attributed to faster transport and new trade opportunities that create additional transport pathways (e.g. Levine & D'Antonio 2002). Despite this rising awareness and recognition of the impacts caused by biological invasions (e.g. Lubchenco et al. 1991; Suchanek 1994), our understanding of the patterns and processes driving marine introductions is limited (e.g. Carlton 1996, 2001; Hewitt 2002; Ruiz & Hewitt 2002).

As an island nation, New Zealand is reliant on trade, and is particularly exposed to invasions of species from overseas (see Cranfield et al. 1998). As a consequence, there exists a heightened awareness of the prevalence and consequences of biological invasions, to the extent that central government and regional councils have dedicated expenditures to prevent and mitigate the impacts of invasions. The Biosecurity Act 1993 provides a sound legislative framework for the management of biosecurity risks (e.g. Hayden & White 2003), but the New Zealand biosecurity system has previously been primarily focused on terrestrial and, to a lesser extent, freshwater ecosystems with limited marine capacity (Biosecurity Council 2003; Hewitt et al. 2004).

Marine biosecurity has had a relatively short history in New Zealand. The former Ministry of Agriculture and Fisheries began an evaluation of ballast water as a vector threat in the early 1990s and subsequently transferred responsibility to the then newly created Ministry of Fisheries (MFish) in 1998. The New Zealand Biodiversity Strategy (Department of Conservation 2000) and subsequent funding package recognised the significant linkages between biodiversity and biosecurity. Specific 'aquatic' biosecurity issues were identified, resulting in the identification of five primary areas for expanded marine biosecurity research and policy development: risk profiling and assessment; management tools for vector threats; baseline information to support border control; surveillance for marine pests; and the development of incursion-response capability. This funding package established an annual marine biosecurity budget of c. $2.4 million per annum and a team of 6.5 full-time equivalent staff (FTEs).

With the development of the Biosecurity Strategy (Biosecurity Council 2003), government agreed to the establishment of a cross-sectoral, 'end-to-end' biosecurity system, with a single line of accountability vested in what is now the Ministry of Agriculture and Forestry (MAF). One key decision was to move away from sectoral (e.g. plants, animals, forests, marine, health) divisions and shift to intervention points (preclearance and post-clearance). A second key decision was to transfer marine biosecurity delivery from the MFish to MAF as of November 2004. In the meantime, four explicitly marine expectations were identified within the Strategy. Similarly, four expectations relating to science integration and delivery to the biosecurity system were identified. As a direct result, government agreed to a significant investment in enhanced marine biosecurity delivery in the 2004/05 budget, leading to an increase in marine biosecurity expenditure of almost 300% (c. $6.9 million per annum), representing c. 4% of biosecurity expenditure (Hewitt & Bauckham 2004). While this is much less (percentage-wise) than the economic contribution of marine primary industries to GDP, it is a large improvement over previous investment.

The purpose of this short review is to describe the current state of marine biosecurity research in New Zealand and to identify the current priorities in central government and gaps that exist to aid in developing both strategic and operational programmes of marine invasion management.

Chad Hewitt has joined Biosecurity New Zealand as the Senior Science Advisor – Marine in the Strategic Science Group. In this role he will provide scientific advice and expertise to the new authority on strategic marine-science issues and will oversee the marine-focused strategic science programme. Prior to moving to MAF at the beginning of November 2004, Chad was the Chief Technical Officer – Marine Biosecurity, Ministry of Fisheries. In this role he was responsible for the management of marine incursions within the New Zealand EEZ and developing and managing the marine invasive-species research portfolio. Chad has an extensive background in the field of marine bio-invasions both in the United States and Australia, extending over a period of 18 years. He was recruited from the Australian CSIRO Centre for Research on Introduced Marine Pests (CRIMP), where he was leader of the Invasion Processes Program since 1995. He holds a BA from UC Berkeley and a PhD from the University of Oregon in the Ecology of Marine Biological Invasions. Chad may be contacted at Chad.Hewitt@maf.govt.nz

Current state of marine biosecurity research

A cursory evaluation of Aquatic Science and Fisheries Abstracts (ASFA) and the New Zealand Marine Science Society Annual Reviews since 1996 indicates that New Zealand researchers have actively published on all aspects of invasion biology—from descriptions of new species arrivals, analyses of distribution and association with vectors, to developing management regimes and policy (Fig. 1). Some 285 publications were identified, authored by more than 300 researchers. The majority of publications in the primary literature describe new invasions or the biogeography of introductions, while management- and policy-oriented information has been primarily published as technical reports or in conference proceedings. Few papers examine invasion processes, specifically relating to vectors, invasion success, or impacts.

Marine biosecurity research has been dominated by the Cawthron Institute and the National Institute of Water and Atmospheric Research (NIWA). These two organisations comprise more than 70% of the publications and contribute more than 80% of the management/policy-oriented papers. In contrast, New Zealand academic institutions (universities, museums) have yet to significantly engage this research agenda. In part, this may be a result of central government's science purchasing arrangement, whereby science is purchased in a competitive market.

Both the Cawthron Institute and NIWA have developed large marine-biosecurity programmes. Cawthron has focused on many aspects of the invasion process including risk assessment frameworks (Shipping Explorer); vector evaluations (ballast water, sea chests, and hull fouling; and domestic aquaculture movements); vector treatment options (e.g. ballast-water heat treatment, ballast-water discharge areas; verification of ballast exchange); and introduced-species impacts (e.g. *Undaria pinnatifida*). In addition, their micro-algal work with harmful algal blooms has strong linkages to biosecurity work.

NIWA's existing biological (information and specimen) and physical data holdings, coupled with a pool of taxonomic expertise, made them well placed to implement the MFish programme of National Baseline Surveys in ports and marinas, and to help establish a surveillance network to aid in early detection of new species arrivals. They have recently established a National Centre for Aquatic Biodiversity and Biosecurity, which aims to form a consortium of organisations, specialists, and communities involved with aquatic biodiversity and biosecurity.

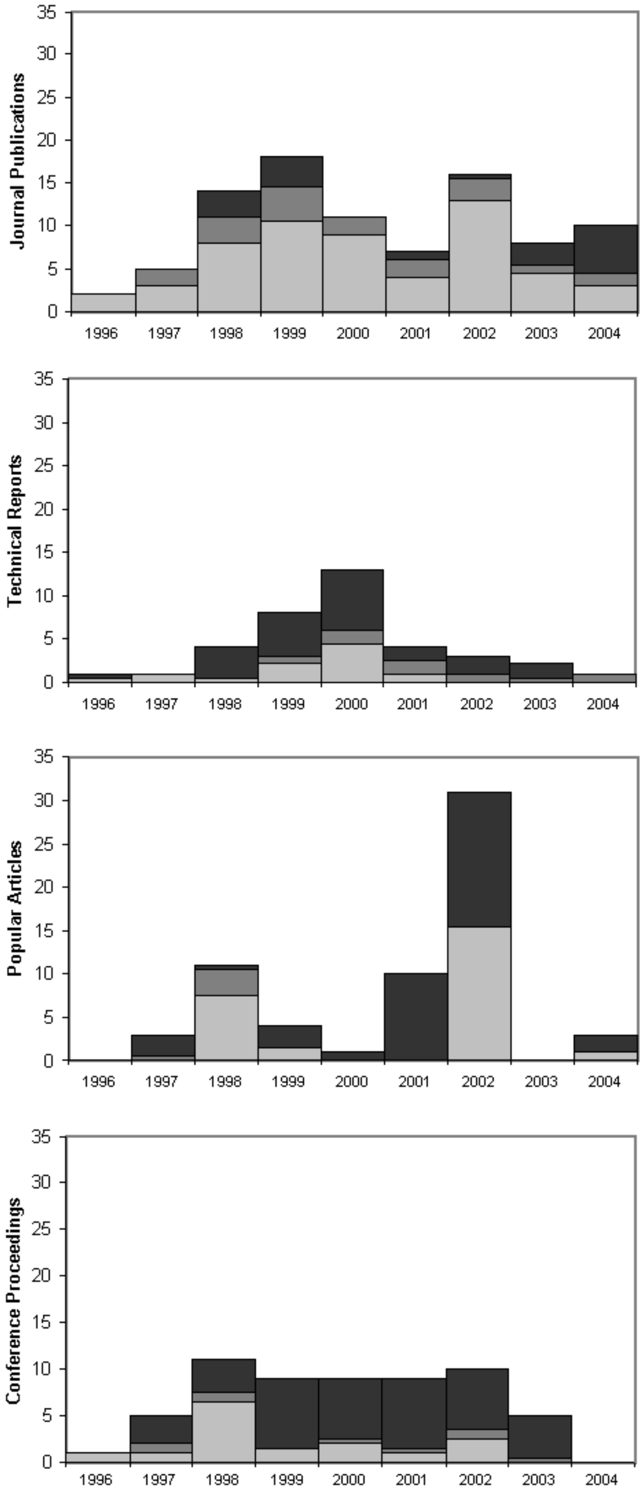

Figure 1. New Zealand marine biosecurity publication rate for 'journal publications' (peer-reviewed journals, book chapters, books), technical reports, popular articles, and conference proceedings between 1996 and 2004. Publications are categorised into patterns (description, biogeography, association with vectors; light grey), process (survival, risk assessment, invasion success, impact assessment; dark grey), or management/policy (management applications, decision frameworks, incursion responses, policy development; black). Overlaps between categories, where a single paper had aspects of more than one category, were scored equally across categories to sum to one. The bibliography is available from the author on request.

Role of science in marine biosecurity management

The role of science in informing public policy has been variously debated, highlighting both positive and negative aspects (e.g. PCE 2003). It is generally agreed, however, that science is a critical component of the biosecurity system (Biosecurity Council 2003). The various roles of research provision, information holder, and provider of advice are unquestioned. It is the dynamic tension between who should determine strategic research directions and the extent to which operational concerns should drive research investment that remain most controversial. Biosecurity delivery by central government is only one funding stream for biosecurity research; the Foundation for Science, Research and Technology (FRST) manages several funding portfolios relating to biosecurity research. These funding bodies will have varying desired outcomes, resulting in differing opinions as to strategic direction.

As a result, the Ministry of Research, Science and Technology (MoRST) has agreed to lead the development of a Biosecurity Research Strategy in support of the Biosecurity Strategy by the end of 2004 (Penman 2004). Similarly, FRST has identified three specific Target Outcomes relating to biosecurity delivery: incursion management; management of existing pests (both within the Ecosystems portfolio); and effective biosecurity systems across sectors (within the Sustainable Resource Use portfolio). This Target-Outcome approach will probably result in proposals for sector-focused biosecurity-Outcome-Based Investments (OBIs) with a 10- to 12-year lifetime. The OBI structure has the potential to guarantee surety to research providers, develop strategic research directions, while simultaneously engaging end-user participation (and co-funding) to identify more pragmatic, operational outcomes. The OBI structure also identifies a move towards more collaborative relationships between research providers.

Concerns over the overlaps between strategic and operational research activities, specifically over the direction of research are high. In the proposed OBI structure, however, the governance arrangements being proposed are likely to both identify longer-term applied research directions (e.g. single-species pest-management tools) while also enhancing synergies between more non-applied 'blue-water' research and the potential derivation of applied outcomes.

Current priorities in central government

The Invasion Process (Fig. 2) provides a simple model for discussing marine-biosecurity research directions and needs, specifically those activities (and gaps) that provide clear management outcomes. The divisions between pre-border (pre-clearance) and post-border (post-clearance), while somewhat artificial in the marine context, represent the intervention point management structure within MAF and clearly map to the invasion process.

Pre-clearance

'Prevention is better than cure' remains the catch-cry of the new biosecurity system, to the extent that the majority of marine biosecurity funding is oriented towards preventing the entry of species through risk assessment and vector management (Hewitt & Bauckham 2004; Hewitt et al. 2004). As a direct result, our ability to predict new (or likely) invaders is of critical importance to success. Many of the proposed methodologies for predicting new invaders (e.g. Hayes & Sliwa 2003) provide useful direction, however these rely on overseas knowledge that is lacking in many regions.

The clearinghouse functions agreed under the Convention for Biological Diversity (CBD COP7, Decision VII/23, Article 18, paragraph 3) and supported by other international instruments (e.g. International Convention for the Management of Ship's Ballast Water and Sediments) will reduce the levels of uncertainty. Similarly, the outcomes of such projects as Oceans Biodiversity Information System (OBIS) and the UNDP/GEF/

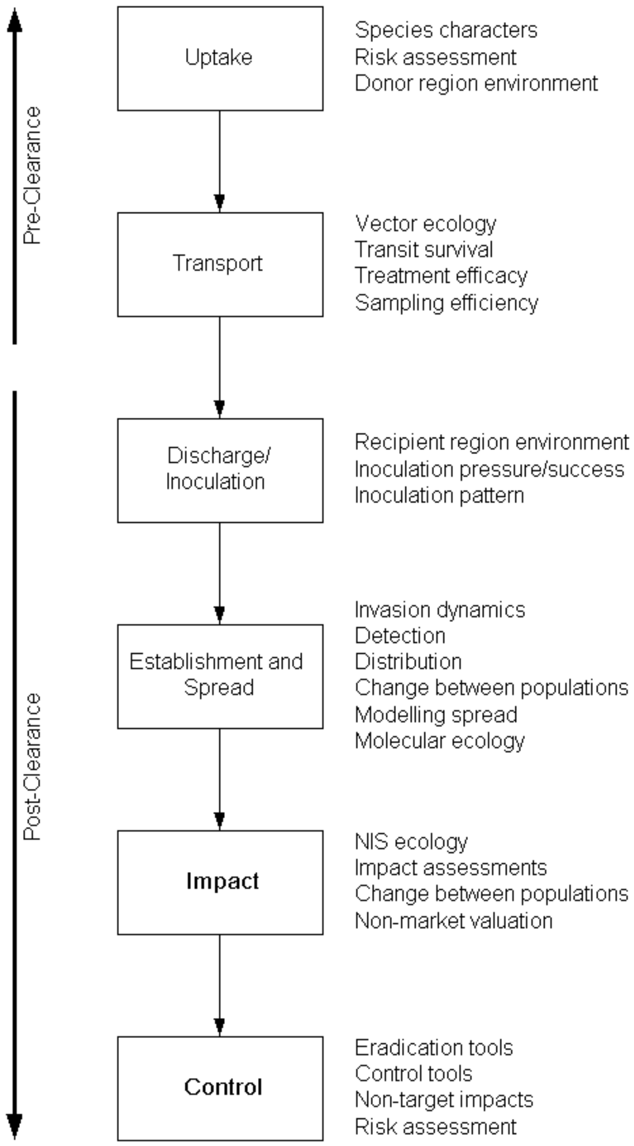

Figure 2. The invasion process with alignment to the Pre-Clearance and Post-Clearance management structure and research activities. NIS – Non-indigenous species.

IMO Global Ballast Water Research Programme will increase our knowledge of invasive marine species.

Transfer of the marine-biosecurity function to MAF may result in a stronger relationship between species risk evaluation and border controls, but the marine approach to risk evaluation of vector (transfer vehicle, e.g. ballast water, hull-fouling, aquarium trade) and pathway (linkage between donor and recipient region, e.g. trade route) is driven by the lack of a certain border. Unlike terrestrial and freshwater systems, marine vectors expose the New Zealand coastal environment to risk before the vessel is inspected at the dockside. Consequently, vector and pathway risk evaluation on a per-voyage basis must be associated with appropriate management options, and these management options must be monitored to determine the extent to which we achieve stated goals.

Rapid identification of species is critical, contributing to developing an understanding of the invasion process, the monitoring of border-management regimes, determining border slippage, and aiding early detection of new incursions. Current technologies are predisposed to target species approaches, but molecular tools are developing rapidly, with a clear indication that large-scale screening for thousands of taxa within an environmental matrix of multiple species (Scolin et al. 1999; Deagle et al. 2003) can occur within a relatively short timeframe. Dip-stick methods of *in-situ* identification are also possible and highly desirable for border-control activities. DNA chip technology is becoming an important area of high-throughput research in basic biological and disease pathways. The technology used to generate DNA chips is evolving rapidly, with the development of solid phase PCR on glass surfaces with no primers freely diffusing in a solution (Adessi et al. 2000).

Significant efforts overseas and in New Zealand have parameterised the risks associated with ballast-water discharges (e.g. Carlton 1989; Taylor et al. 2000) and have begun the process of identifying treatment solutions (Mountfort et al. 1999a,b). This work has taken more than 20 years of sustained research, and will require several more. The new International Convention for the Management of Ship's Ballast Water and Sediments (IMO 2003) provides a basis for global management, but is only a starting point. A continued need to develop appropriate risk-management frameworks to aid sampling and decision-making processes exists, as do the requirements for rapid determination of compliance to regulated standards. Initially, the standard is ballast exchange at sea, consistent with the New Zealand Ballast Water Import Health Standard (see Hayden & White 2003); the Convention identifies the phase-in of a discharge standard (density of organisms per m^3).

A similar level of effort is now required to parameterise the risks associated with hull-fouling, sea-chests, and other hull niches. The marine biosecurity system (MFish) has begun this process and will attempt a broad-scale evaluation across all vessel types. The basic taxonomic-identification needs associated with this sampling process, however, are considerable.

Post-clearance

Post-clearance activities will include all those aspects of the invasion process that occur after the inoculation into the marine environment (Fig. 2). In many instances, clearance activities consistent with current MAF activities will be applicable. For example, the entries of marine aquarium species are currently managed and 'cleared'. The transfer of marine function into MAF will only act to strengthen these activities. The unmanaged hitchhikers and accidental transfers will continue to be the focus of marine-biosecurity efforts.

The current marine biosecurity funding (MFish) has established a National System of Baseline Surveys and Resurveys as a critical component of operational delivery (Hewitt et al. 2004; Inglis in press). These baselines provide an indication of the existing state of invasions and distributions, against which management actions can be evaluated as additional surveillance and resurveys occur. The baseline evaluations provide both biosecurity and biodiversity outcomes. They are currently restricted to primary international trading ports, but the new funding has identified an expansion to domestic ports. The identification of vector-based 'hotspots' (those identified from a fine-scale evaluation of shipping activities) and comparison with survey-based species distributions will also enable a fine-tuning of the survey design for subsequent monitoring surveys.

One primary need is to expand our knowledge of invasions in low human-impact regions, such as areas of high biodiversity value. One specific example is the increasing recognition of threats to Antarctic and Southern Ocean sites (Lewis et al. 2003, 2004; Frenot et al. in press). These evaluations will be costly, but have significant lateral benefits. One driving question in invasion biology is the identification of determining factors leading to invasion success (Carlton 1996). The relationships between invasions and inoculation volume (number of organisms), inoculation frequency, diversity of recipient biological community, and frequency and intensity of disturbance are confounded in port environments, but can be teased apart in more 'pristine' regions.

Similarly, establishing efficacious and sufficient surveillance to detect the early incursions of known targeted high-impact species is of importance. These activities rely on the ability to identify target species (risk assessment) and associated spatial mapping of values. Research needs exist for early detection and rapid identification. Further, the establishment of value maps for the New Zealand EEZ that describe the locations of critical economic, environmental, social, and spiritual values will require significant economic and social science input into developing appropriate non-market valuations.

Bearing in mind that FRST is unable to fund contingency and incursion-based operational research, the focus on developing models of rates and locations of spread, coupled with eradication-response tools, is necessary for a functional incursion-response and pest-management system. MAF has a well-established incursion-response system for terrestrial activities. Work is now underway to determine the synergies between environments and to put in place equivalent, if not congruous, systems.

Better understanding of the impacts of introduced species in the marine environment is one obligation under the CBD and will inform government, senior officials, and managers in future prioritisation of funds. The likely impacts of marine invasions in New Zealand are typically surmised from overseas evaluations, leading to equivocal arguments. Developing clear guidelines for impact evaluations, and undertaking to determine the current state is a key gap.

In many ways, the challenges facing marine biosecurity are integrally linked to those for marine biodiversity—sampling, identification, and mapping (Nelson & Gordon 1997). The difficulty with representatively sampling native biodiversity at appropriate scales is exacerbated by the significant taxonomic overheads associated with large-scale sampling programmes. An estimated 80% of marine species are yet to be named, and taxonomic specialist capability is decreasing annually. Consequently, the needs for well-curated biological collections and databases of native species information are apparent, as is the need to develop enhanced taxonomic capability. FRST will also invest to maintain and develop the underlying research capacity that will enable operational agencies to respond appropriately to biosecurity problems, new threats and incursions.

Conclusion

Perhaps the greatest threat to achieving biosecurity outcomes will be ignorance—of what is happening overseas, of what is entering the country, of what drives invasions and impacts, and of what we can do about them once they are here. Given the relatively recent status of marine biosecurity in New Zealand and overseas, the gains we have made are tremendous, yet the path ahead is anything but clear. In order to achieve the expectations identified in the Biosecurity Strategy (Biosecurity Council 2003), significant research gains must be made.

MoRST-led development of a Biosecurity Research Strategy has the potential to significantly align central government funding for marine biosecurity delivery. Coupled with the development of FRST-funded OBIs and enhanced marine capability within MAF, the means to address the gaps will be partially in place.

The biosecurity system comprises central-government agencies (with MAF as the lead agency), regional councils, research organisations and Universities, the private sector, non-governmental organisations, and the public. Consequently, funding from biosecurity agencies must be complemented from the public good science portfolio and the private sector in order to guarantee sufficient resources and buy-in.

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