Regional spread of marine non-indigenous species, a pathway modelling approach in New Zealand

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LIST OF ACRONYMS AND ABBREVIATIONS

ANZECC	Australian and New Zealand Environment and Conservation Council
ASA	Australian Ship Owners Association
AUTEC	Auckland University of Technology Ethics Committee
CDFG	California Department of Fish and Game
CRV	Connectivity ranking value
CV	Connectivity value
DCS	Dispersion cluster spread
EC	European Commission
EPA Victoria	Environmental Protection Authority Victoria
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization
FMEA	Failure Mode and Effect Analysis
GISP	Global Invasive Species Program
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
IT2FL	Interval type–2 fuzzy logic
IT2FS	Interval type–2 fuzzy set
LWA	Linguistic weighted average
MAD	Mean advection distance
MAF	Ministry for Agriculture and Forestry Biosecurity New Zealand.
MoRST	Ministry of Research, Science and Technology
NIS	Non-indigenous species
NISC	The National Invasive Species Council
NRC	United States National Academy of Sciences' National Research Council
NZGM	New Zealand Greenshell™ Mussel
OSPAR	The Convention for the Protection of the Marine Environment of the North East Atlantic
PPD	Propagule pelagic duration
PRV	Priority ranking value
RPN	Risk Priority Number
SA/SNZ	Standards Australia/Standards New Zealand
SPC	Small powered craft
TDC	Tasman District Council
TKE	Turbulent kinetic energy
US	United States
USEPA	United States Environmental Protection Agency

ABSTRACT

The devastating ecological and socio-economic impacts of non-indigenous species (NIS) have been documented worldwide, highlighting the need for effective management. In contrast to terrestrial and freshwater ecosystems, management of marine NIS is relatively new and usually focused on preventing initial introductions at national (e.g., in New Zealand) and state (e.g., in the United States, Australia) borders. However, the intrinsic 'leakiness' of these borders and thus, inevitable arrival of new NIS, in addition to the potential spread of those already established, makes regional management an integral component of marine biosecurity programmes.

Even in New Zealand, a leading country in marine biosecurity, the implementation of regional strategies has been difficult, putting New Zealand's iconic values such as marine biodiversity and aquaculture, at risk. This thesis aims to model and analyse recreational boating, aquaculture and natural currents as pathways for the regional spread of NIS within New Zealand. It uses Golden Bay and Tasman Bay as a case study and applies existing and new modelling and prioritisation approaches.

Chapter 1 presents a succinct introduction to some basic concepts of marine invasions and risk assessment. The term biosecurity is presented, followed by an outline of this system in New Zealand, with an emphasis on the post-border component. The chapter describes Golden Bay and Tasman Bay, including aspects related to its marine biosecurity.

Chapter 2 develops a comprehensive conceptual model representing a range of sequential events that could lead to the release of a NIS into the environment when transported by a recreational vessel to a new area. The model was developed using fault tree analysis and expert input. The results show the complexity of the marine invasion process via recreational vessels, even when only one step of the process is considered. They also highlight the role that other components of the vessel besides the hull could have in the spread of NIS and identify user awareness as a determining factor in the release of a NIS into a new area.

Chapter 3 characterises recreational boating in Golden Bay and Tasman Bay. It introduces the connectivity ranking value and priority ranking value concepts to identify areas within the study region where marine biosecurity surveillance should be a priority. The information required for this analysis was generated through a mail survey with recreational boat users and estimates from a group of experts, which were combined using interval type–2 fuzzy logic. The results show that areas such as Nelson and the Abel Tasman National Park would be comparatively more important than other regions in the spread of NIS within the region.

Chapter 4 uses the Greenshell mussel aquaculture industry to model its potential role as a pathway for NIS. The results identify the components (e.g., farms, hatcheries) and processes, as well as potential vectors (vessels, gear, spat) that define mussel aquaculture as a potential pathway for NIS in this region. The results show that, based on the likelihood of 1) movement between locations, 2) retention of fouling, sediment and/or water, and 3) cleaning between locations, spat is the most important vector of this pathway and thus, a management priority. This chapter also describes some overlaps between mussel aquaculture and other

potential pathways such as commercial shipping, recreational boating, public aquaria, and coastal currents.

Chapter 5 presents a 2D advection-diffusion model that was used to investigate the role of currents in the spread of NIS within Golden Bay and Tasman Bay. A current field of 13 years of hourly data is used to analyse the dispersal patterns for four planktonic propagule durations (PPD) between 1–30 days released at 11 different locations. High variability in the results associated with release location, PPD and time period, indicates that the fate of propagules will be species and spatio-temporally dependent. The results present the connectivity pattern for each release location, identifying the role of these locations as source and/or recipients.

Chapter 6 presents a brief summary of previous chapters, highlighting their main aspects. It conducts an initial integral assessment across the pathways recreational boating, aquaculture, and natural currents in the study region by combining the connectivity patterns identified in previous chapters. The results show that when considering all these pathways together, the entire region is interconnected creating a potentially ‘efficient NIS pathway’ (i.e., with the ability to spread a NIS from any region throughout the entire region). Future application of the concepts and results are suggested.

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

May 20, 2013.

Hernando Acosta Cajiao

STATEMENT OF CO-AUTHORSHIP

Some of the work presented in this thesis has already been published or is to be submitted for publication in international peer-reviewed journals.

Chapter 2. Part of this work has already been published as:

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Acosta, H. (80%) – Wu, D. (10%) – Forrest, B.M. (10%). Acosta, H. contributed with the concept, design and implementation of the project, and preparation of the manuscript. Wu, D. contributed mainly with guidance and supervision of the correct interpretation and application of the interval type-2 fuzzy theory and relevant computer code. Forrest, B.M. suggested ideas for analysing the data and assisted to expand the management aspect of the manuscript. He also contributed with refinement and presentation of the manuscript.

Chapter 5. A modified version of this chapter is to be submitted to *PLOS ONE* as:

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Acosta, H. (80%) – Forrest, B.M. (10%) – Knight, B. (10%). Acosta, H. contributed with the concept, design and implementation of the project, and preparation of the manuscript. Knight, B. was responsible for adapting the hydrodynamic model to the needs of the study and contributed to the design of the dispersal model and refinement of the manuscript. Dr. Forrest suggested the case-study species and some of the analyses conducted. He also contributed to the development of the examples and with editorial input.

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Chapter 1: General Introduction

1.1 INTRODUCTION TO MARINE NON-INDIGENOUS SPECIES

Non-indigenous species[1] (NIS) are those that have been transported, intentionally or unintentionally via human-mediated means, into regions where they did not previously exist (Hewitt et al. 2010). They have the potential to cause significant damage to the environment, economy, and/or human health, and when they do, NIS are referred to as 'invasive' (Williamson and Fitter 1996, Boudouresque and Verlaque 2002). NIS are considered a main cause of biodiversity loss and global environmental change (Vitousek et al. 1997, Mack et al. 2000, Occhipinti-Ambrogi and Savini 2003), and their increasing introduction rate has been directly related to the growth of international trade (Carlton and Geller 1993, Cohen and Carlton 1998, Levine and D'Antonio 2003, Pysek et al. 2010). Global change caused by NIS is likely to increase in the future if no action is taken at all levels to control the introduction and establishment of these species and manage those already introduced (EC 2011).

While NIS have been extensively documented and studied in terrestrial and freshwater environments, (e.g., Elton 1958, Mollison 1986, Usher et al. 1988, Williamson 1996, Simberloff and von Holle 1999, Mooney and Hobbs 2000, Cadotte and Colautti 2005, D'Antonio and Kark 2002, Hendrit 2007), the study of coastal and marine NIS is a relatively new field. Marine ecosystems are among those most affected by biological invasions worldwide (Grosholz 2005) and there is a growing research interest in this area (e.g., Carlton 1989, Eno 1996, Grosholz 2002, Colautti et al. 2006, Molnar et al. 2008, Rilov and Crooks 2009, Geller et al. 2010, Hewitt et al. 2011). However, our knowledge of the invasion process and dynamics of potential pathways and vectors is still limited, especially when considering the unpredictable behaviour of NIS in new environments (Bomford 2003), large time scale climate oscillations (Hilbish et al. 2010), climate change (Zaouali et al. 2007, Pancucci-Papadopoulou et al. 2011,) and an increasing and variable (usually trade-driven) connectivity at international, regional and local levels (Abdulla and Linden 2008, Floerl and Coutts 2009, Ducruet and Notteboom 2012). This certainly limits our ability to manage marine NIS effectively and efficiently, especially at a regional level, despite the existence of several biosecurity strategies and initiatives implemented across the world (e.g., the international initiatives Global Invasive Species Programme (www.gisinetwork.org) and GloBallast (http://globallast.imo.org), New Zealand's Marine High Risk Site Surveillance (www.biosecurity.govt.nz/biosec), Australia's National System for the Prevention and Management of Marine Pest Incursion (www.daff.gov.au/mp/national_system), Ireland's Invasive Species Programme (http://invasivespeciesireland.com)).

[1]Other terms generally used interchangeably with non-indigenous include adventive, alien, exotic, introduced, non-native (e.g., US Congress, Office of Technology Assessment 1993, Chapman 2001).

1.1.1 The invasion process

Biological invasions have been conceptualised as a continuum of distinct steps, with the number and names of these steps varying among authors (e.g., Sakai et al. 2001, Lockwood et al. 2005). The differences are mainly the result of using either broad, or narrow and specific steps to describe the same process (see Fig. 1.1). In general, invasions can be seen simply as the result of the three-step process of: 1) introduction, 2) establishment, and 3) expansion or spread (Sakai et al. 2001, Ward et al. 2006). This description considers the impact of the invasion to be part of the establishment and spread. However, some authors define impact as a separate step that occurs alongside and/or after the spread (e.g., Kolar and Lodge 2002).

Introduction encompasses the entrainment of a species by a vector in its native range, transport of the species to a new region, and release of the species into this new region (Kolar and Lodge 2001). Establishment is reached when the NIS is able to initiate and maintain self-sustaining populations in the new environment (Sakai et al. 2001). Often established species maintain low population levels for a period of time, usually known as the lag phase (Mack 1985, Kowarik 1995), before beginning the final step of the invasion. Spread, the final step, implies an increase in population sizes and geographical range expansion causing damage to the environment, economy, and/or the human health in the region (Executive Presidential Order 1999, Sakai et al. 2001).

The introduction of NIS into a new region can be primary or secondary. Primary introduction refers to the arrival of an NIS in a new location directly from its native range, while secondary introduction refers to the spread from one region of introduction to other regions (OSPAR 1997, Carlton 1999, Sakai et al. 2001, Minchin and Gollasch 2002). For example, molecular data have determined that although the invading cladoceran *Cercopagis pengoi* is native to the Ponto-Caspian basin, the populations present in the Great Lakes (USA) are likely to come from a secondary introduction of propagules from the Baltic Sea (Cristescu et al. 2001). Similarly, there is some evidence that the introduction of the Asian kelp *Undaria pinnatifida* to Australia (Victoria State) and Argentina has been the result of secondary introductions from New Zealand (Uwai et al. 2006).Primary introductions usually occur across trans-oceanic and intercontinental distances between provinces and bioregions, generally geographically isolated by major oceanic, landmass, or climatic barriers (Ruiz et al. 2000a,b, Neil et al. 2005).

Secondary introductions can occur at a similarly large scale (e.g., Cristescu et al. 2001) but they are more common at regional and local scales (e.g., the southward spread of the European green crab *Carcinus maenas* from mainland Australia to Tasmania across the Bass Strait (Thresher et al. 2003) and the spread of *U. pinnatifida* across North Island and South Island ports and coastal locations in New Zealand (Uwai et al. 2006, Floerl et al. 2009)). Secondary introductions usually involve a wider range of spread mechanisms including natural spread (Jansson 2000, Occhipinti-Ambrogi and Galil 2004, ICES 2005) and can act separately, or alongside each other (Minchin and Gollasch 2002).

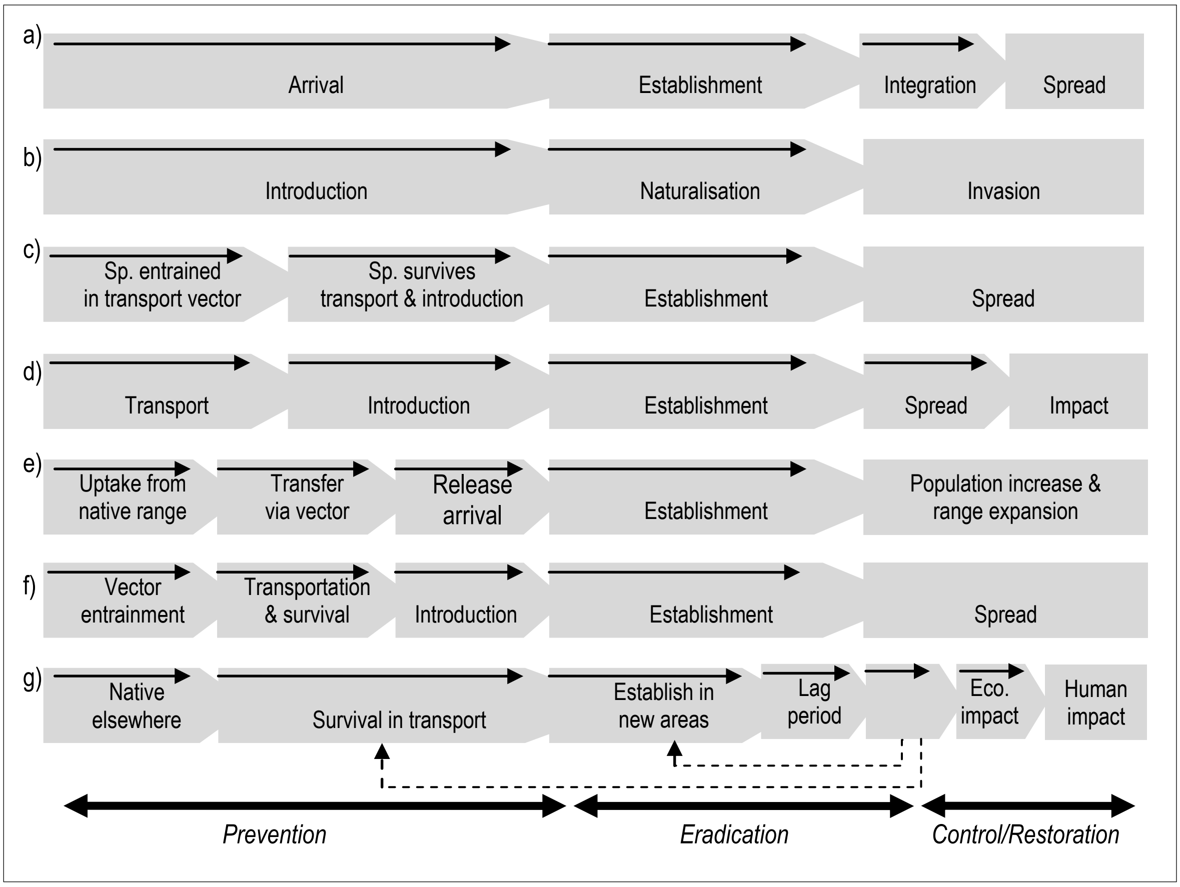

Figure 1.1 The biological invasion process. The steps of the invasion process *sensu*: a) Vermeij 1996, b) Richardson et al. 2000, c) Kolar and Lodge 2001, d) Kolar and Lodge 2002, e) Lockwood et al. 2005, f) Miller and Ruiz 2009, and g) Sakai et al. 2001. Some stages are more relevant for prevention and others are more relevant for issues of control and restoration (Sakai et al. 2001). Eco.= Ecological. Note that the size of the boxes is no indication of the length of the steps.

1.1.2 Invasion pathways and vectors

A wide range of marine NIS spread mechanisms have been identified to date including shipping, aquaculture, and the aquarium trade (e.g., Carlton 2001, Hewitt et al. 2004, Minchin et al. 2005), but a 'complete and unique' list does not exist. This is because different authors use different categories to group the spread mechanisms. For example, while Minchin et al. (2005) describes fisheries and marine aquaculture as two different categories, Carlton (2001) groups them under the same one.

In a marine context, the term vector is usually applied to the physical means or agent causing a species translocation, while a pathway may refer to the vector, the reason why the species is moved, and the route followed when moving the species (Carlton 2001). However, these terms are not always used consistently and some authors treat them as synonyms (e.g., CDFG 2008). Even Carlton (2001), a key reference for these terms, 'for clarity' avoided the term pathway. Similarly, some authors also use the term 'sub-vector' to be specific when a spread mechanism has several components (e.g., GISP 2008, Hewitt et al. 2009, National Research Council 2008, Ruiz et al. 2011). For example, some authors considered the vessel to be a vector and vessel hull fouling and ballast water to be sub-vectors (e.g., GISP 2008, Ruiz et al. 2011). In this thesis the terms, vector and pathway, will be used consistently with the above definitions given by Carlton (2001).

A pathway may include several vectors involved in a species translocation. Similarly, vectors may change over time and may differ regionally (Galil et al. 2009, Minchin et al. 2009). A recent European classification based on the frameworks proposed by Hulme et al. (2008) and Molnar et al. (2008) identified five categories of marine NIS pathways: 1) shipping, 2) aquaculture, 3) corridors, 4) aquarium trade, and 5) other (Katsanevakis et al. 2013). This classification targets only primary pathways (i.e., the natural spread of secondary introductions is not included). A more recent and comprehensive list was produced by Hewitt et al. (2004) based on the group of vectors presented by Carlton (2001). This list has nine categories (e.g., ships, aquaculture fisheries, research and education) encompassing over 20 potential pathways, and while applicable elsewhere, it was developed specifically based on international and domestic pathways relevant to New Zealand (Table 1.1).

Despite differences in categorisation, aquaculture and commercial shipping are considered the main NIS vectors globally (Ruiz et al. 1997, Minton et al. 2005, Molnar et al. 2008, Hewitt et al. 2011), but at a regional level other vectors (e.g., recreational vessels) may be more critical (Minchin et al. 2006a,b, Floerl et al. 2005a, Molnar et al. 2008).

Consistently, marine biosecurity research and management has focused on the globally significant vectors aquaculture (e.g., Minchin 1996, 2007a, Naylor et al. 2001, ICES 2005, Denny 2008, Morrisey et al. 2011) and shipping, especially ballast water, external fouling and sea chest (e.g., Carlton 1985, Ruiz et al. 1997, Coutts and Taylor 2004, Lodge et al. 2006, Hewitt and Campbell 2007, Hopkins and Forrest 2010a). Other vectors nonetheless, may be essential for specific NIS. The highly invasive strain of the macroalga *Caulerpa taxifolia* for example, was initially introduced to the Mediterranean and California (and probably also to the New South Wales (Creese et al. 2004)) via the aquarium trade (Jousson et al. 1998). Although there is an increasing interest in introductions of this type (e.g., Padilla and Williams 2004, Semmens et al. 2004, Bolton and Graham 2006), and other quantitatively smaller (and thus less evident) vectors such as recreational boating (e.g., Hewitt and Campbell 2001, Ashton et al. 2006a, Floerl et al. 2009, Davidson et al. 2010, Lacoursière-Roussel et al. 2012) and live seafood (e.g., Chapman et al. 2003, Weigle et al. 2005), research is still limited. This information deficit makes NIS management complex and difficult.

1.1.3 Marine non-indigenous species impacts

Marine NIS are considered a leading cause of biodiversity loss (Lubchenco et al. 1991, Vitousek et al. 1997, Carlton 2001, Bax et al. 2003, Hewitt 2003, Hewitt et al. 2006), with a wide range of potentially irreversible ecological and socio-economic detrimental impacts being documented worldwide (e.g., Kelly 1993, Cranfield et al. 1998, Galil 2000, Ambrogi 2001, Grosholz 2002, Walton et al. 2002, Lewis et al. 2003, Wrigth and Gribben 2008, Rilov and Crooks 2009, Gribben et al. 2009, Wright et al. 2010, Thomsen et al. 2011). Specifically, it is recognised that marine NIS change physicochemical conditions in the invaded ecosystem (e.g., Wallentinus 2002, Hopkins 2002). They compete with native species (e.g., Britton-Simmons 2004, Ross et al. 2004, Gribben and Wright 2006) and prey upon them (e.g., Eldredge 1994, Hoff and Bollens 2004, Ross et al. 2004). Further problems arise from the accompanying complement of non-indigenous diseases and parasites to which native species may not be resistant (Torchin et al. 2003, Vignon and Sasal 2010). Consequently, marine NIS have been associated with food web and community changes (e.g., Neira et al. 2005, Holloway and Keough 2002), as well as modification of native genetic pools (e.g., Daehler and Strong 1997, Ayres et al. 1999).

The presence of NIS may reduce income derived from aquaculture, commercial and recreational fishing, water sport industries, and domestic and international tourism (Galil 2000, Streftaris and Zenetos 2006, Reid et al. 2009). The effects of marine NIS can therefore be described as socio-economically deleterious (Carlton, 1996, Pimentel et al. 2000, Colautti et al. 2006). For example, although it is now considered to have been a temporary collapse (Oguz et al. 2008), the invasion of the comb jelly *Mnemiospsis leidyi* in the Black Sea is believed to have reduced the anchovy fisheries from hundreds of thousands of tons to tens of thousands, thus, collapsing a fishery worth US$ 250 million per year (Harbison and Volovik 1994, Knowler 2005). Similarly, Lafferty and Kuris (1996) estimated the potential economic impact of the introduced European green crab in the US to be around US$ 44 million annually.

The Northern Pacific seastar *Asterias amurensis*, the Asian kelp *Undaria pinnatifida*, and the toxic dinoflagellate *Gymnodinium catenatum* are believed to have cost the shipping, marine aquaculture and fishing industries in Australia millions of dollars annually (Hewitt et al. 1997). Swarms of the large NIS jellyfish *Rhopilema nomadica* can reach the coast of Turkey each summer and sting bathers, clog fishing nets, and smother catches (Gülşahin and Tarkan 2011). Tourism reduction as a result of NIS algae fouling the coastline in Maui (Hawaii) is estimated to cost about US$ 20 million annually (NISC 2006). Similarly, the Japanese wireweed *Sargassum muticum* is considered a potential threat to the tourism industry in Great Britain because of its aesthetic impact on coastlines (Reid et al. 2009).

In some cases however, at least from a socio-economic point of view, the effects of marine NIS may be regarded as positive. These effects include the aesthetic value of introduced species and the value of fisheries based on NIS (Hewitt and Hayes 2001). Some of the Erythrean species (e.g., the swimming crab *Portunus pelagicus*, the yellow striped mullet *Upeneus moluccensi*, and the lizardfish *Saurida undosquamis*) that invaded the Mediterranean via the Suez Canal have become commercially important for the region (Oren 1957, Golani and Tuvia 1995, Galil 2007).

Similarly, the Pacific oyster *Crassostrea gigas* introduced accidentally into New Zealand in the late nineteen-sixties (Dinamani 1971) is now one of the main aquaculture industries (NZ Govt. 2007). Fisheries for established NIS can nonetheless also have adverse effects on the ecosystem due to the destructive nature of the fishing gear used (Eno et al. 1997). Also, exploiting NIS as an economic resource might encourage communities to protect potential invasive species and facilitate incorporation of such species into the local culture, generating additional management problems (Nuñez et al. 2012).

Table 1.1 List of international and domestic pathways of relevance to New Zealand (from Hewitt et al. 2004).

Category	Pathway
Ships	Ballast water and sediments Hull fouling Solid ballast
Moveable structures (Oil platforms, barges, dredgers, floating docks)	Hull fouling Ballast water and sediments
Other craft (Merchant, fishing, and recreational/leisure)	Hull projections and cavities (sea-chests, thrusters, and internal piping) Hull boring Aquatic cargo (wells and tanks) Anchor/anchor chains/lockers/moorings Scuppers and bulwarks Small craft trailers Dredging spoil Intentional release and stock movements Accidental release Gear movement Discarded nets, floats, traps Discarded packaging materials Discharge of feeds (live, fresh, and frozen) Release of transgenic and GMO species
Wild fisheries	Stock movement Population re-establishment Processing of live, fresh, and frozen products Live bait movement Gear and transport media (water) movement Discarded/lost fishing gear Discard of target and non-target species (bycatch) Live trade for consumption: accidental/intentional release
Aquarium industry and public aquaria	Intentional release Accidental release Untreated aquarium and waste discharge Living food movement
Marine leisure tourism	Live bait movement Accidental/intentional transport and release of fishing catch Diving gear movement Fishing gear (including boots) movement
Research and education	Intentional release Accidental release Water and waste discharges Living food movement Diving gear movement Field and experimental gear movement Restoration, mitigation and rehabilitation
Other	Alteration of water courses and flow regimes Irrigation canals (including saline ponds) Municipal and other waste/water treatment discharges

The potential and realised impacts of marine NIS clearly highlight the need for effective management programmes that prevent their occurrence and mitigate the consequences. Effective management requires a baseline knowledge and understanding of the invasion process, the biology and ecology of the introduced species, and the characteristics of the native and invaded environment, and associated spread mechanisms (Richardson et al. 2003). At present, such information is incomplete if not absent. This, together with the stochasticity of the invasion process (Smith et al. 1999, Wonham et al. 2000) creates large uncertainties in determining the consequences of marine introductions and deciding management options. Uncertainties about marine NIS increase considerably when considering that:

1. except for aquaculture species, not many invasive marine NIS are studied in their native regions (e.g., Grosholz and Ruiz 1996, Muirhead et al. 2008),
2. some NIS may behave in a new and unpredictable fashion when introduced to a place outside their native range (Bomford 2003),
3. some NIS are able to adapt to their new environment (Phillips and Shine 2005),
4. some species may evolve during the invasion process (Marsico et al. 2010).

Hence, management strategies for biological introductions usually advise following decision-making processes based on risk analysis (McNeely et al. 2001, Williamson et al. 2002, Lodge et al. 2006, Hulme et al. 2009).

1.2 RISK AND RISK ASSESSMENT

Risk is a term commonly used in peoples' day-to-day activities as well as in natural, social, and applied sciences. As with invasion biology, the term 'risk' and its derived-terminology have a wide range of definitions and concepts varying not only among, but also within different fields (e.g., WHO/IPCS 2004). For example, while the Merriam-Webster dictionary currently defines risk as 'possibility of loss or injury', the Oxford English Dictionary defines risk as '(Exposure to) the possibility of loss, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility.' For the United States National Academy of Sciences' National Research Council (NRC) risk is 'a concept used to give meaning to things, forces, or circumstances that pose danger to people or to what they value' (NRC 1996). Similarly, in 1999 Standards Australia and Standards New Zealand (SA/SNZ) defined risk as 'the effect the change of something happening that will have an impact on objectives' (SA/SNZ 1999). This definition was later modified in 2009 to 'effect of uncertainty on objectives' (SA/SNZ 2009).

Most of the definitions relate the term risk to negative outcomes, with some even suggesting that risk cannot be directly associated with a positive outcome, opportunity, or success (e.g., Ayyub 2001). However, there are some authors who consider that risk can also encompass the likelihood of an event with positive outcomes (e.g., Hillson 2002). Despite the wide range of definitions of risk, many of them agree that risk is a possibility (i.e., probability) of 'something' happening, where that 'something' usually has negative consequences. Therefore, this thesis uses the term risk as a measure of the probability and severity of adverse effects (*sensu* Lowrance 1976).

Risk assessment is part of the risk analysis process, which is developed around the concept that aspects of the event/activity considered could bring negative consequences. The entire process of risk analysis is comprised of risk assessment, risk management, and risk communication (North 1995, ACS 1998, Byrd and Cothern 2000, Fjeld et al. 2007). Risk assessment is the process of characterising the risk based on the probability of occurrence and consequence (Byrd and Cothern 2000, Fjeld et al. 2007). Risk management is the process where, based on information from risk assessment, decision makers evaluate and compare decision alternatives (Lane and Stephenson 1998). Risk communication entails the exchange of information and opinion concerning risk and risk-related factors among the risk assessors, risk managers, and other stakeholders (Fjeld et al. 2007). For some authors, risk analysis includes a fourth process: risk policy, but as Byrd and Cothern (2000) suggest risk policy should not be considered on its own but as a process embedded into the assessment, management and communication processes.

Risk assessment[2] applied in marine biosecurity comprises the following five steps (Campbell and Hewitt 2008):

1. Identifying endpoints. Endpoints represent the values (e.g., economic, environmental, socio-cultural and human health) the risk assessment is trying to protect (Bartell et al. 1992, Sergeant 2002, Burgman 2005) and should be defined to adequately reflect management goals (USEPA 1998). They can be divided into three broad categories: 1) management goals (defined in terms of goals that, although vague and ambiguous, carry clear social mandate), 2) assessment endpoints (translate management goals into a conceptual model, and satisfy social objectives, but cannot be measured), and 3) measurement endpoints (measureable operational definitions of assessment endpoints and thus of management goals) (Suter 1993). In a NIS risk assessment they are the values that might be affected by the introduction and/or spread of a NIS (Andersen et al. 2004); for example, the persistence of the current population size and structure of great blue heron (*Ardea herodias*) in Cherry Point, Washington, USA (Colnar and Landis 2007).
2. Identifying hazards. Hazards are situations or events that could lead to harm (The Royal Society 1983) under certain conditions. The objective of this step is to assess ‘what could go wrong’. A range of deductive and inductive techniques, many originated in the field of engineering, are commonly used to identify hazards (e.g., brainstorming, checklist, hazard and operability analysis, fault tree analysis, and logic trees). Some of these have also been used in NIS risk assessments (e.g., Hayes 2002a,b, Kolar and Lodge 2002, Gunderson and Kinnunen 2004).
3. Determining likelihood. This step estimates the probability of occurrence of the hazards identified (e.g., the likelihood that a *Didymosphenia geminata* incursion will occur within a New Zealand region (Campbell 2005)). The probability can be indicated quantitatively, semi-quantitatively or qualitatively.
4. Determining consequences. Consequences are the effects that hazards could have on the values represented by the defined endpoints. In NIS risk assessment

[2] ‘Risk assessment’ is often used synonymously with ‘risk analysis’ (Cohrssen and Covello 1989). However, as with many authors (including MAFBNZ (2006)), in this thesis ‘risk assessment’ refers to the process of estimating the probabilities and consequences of hazards.

consequences relate to the potential impact of the introduced species on the value(s) considered (e.g., ecosystem biodiversity, or a particular aquaculture species), but as suggested by Hayes et al. (2004a) there is no currently universally accepted way to measure these. Impacts can be evaluated using empirical data, or heuristic assessment of opinions of expert and/or stakeholders (Campbell 2008, 2009, Hewitt et al. 2010), or a combination of both. The magnitude of consequences of the hazards is assessed in the context of existing controls (SA/SNZ 1999).

5. Calculating risk. Also referred to as risk characterisation (e.g., Colnar and Landis 2007), this step produces a risk estimate by combining the likelihood of hazard occurrence with its consequences. This is calculated for each of the values being protected. Often a risk matrix combining likelihood and consequence values is used to calculate the risk (e.g., Carey et al. 2004, Campbell 2008, SA/SNZ 2009, Gillanders and Ye 2011).

Risk assessment is now widely used in the biological invasion field (e.g., Andersen et al. 2004, Andersen et al. 2005, Allen et al. 2006, Andreu and Vilà 2010, Miller et al. 2010, Simberloff and Rejmanek 2011, Britton et al. 2011). In the marine NIS area the use of risk assessment techniques and approaches has grown significantly since the late nineties (e.g., Hayes 1998, Hallegraeff 1998, Gollasch and Leppäkoski 1999, Hayes and Hewitt 2000, Hewitt and Hayes 2002, Awad et al. 2004, David and Perkovič 2004, Gossett et al. 2004, Floerl et al. 2005a, Colnar and Landis 2007, Campbell 2009, Luo and Opaluch 2010, Hewitt et al. 2011, Thomsen et al. 2011).

International agreements and guidelines, and regional and national legislation and protocols aimed at preventing the introduction and spread of NIS also invoke, or are directly based on, risk assessment approaches. The World Trade Organisation (WTO) agreement on the application of Sanitary and Phytosanitary measures (commonly referred to as the 'SPS Agreement') requires country members to make decisions based on risk assessments (WTO 1994). The European and Mediterranean Plant Protection Organisation (EPPO) developed a pest risk assessment scheme to assess the risk posed by NIS (unintentionally introduced) to cultivated plants (EPPO 1997). The State of Victoria, Australia implemented a risk assessment based ballast water management framework to minimise the introduction of marine pests into Victorian State waters from high-risk domestic ballast water discharge (EPA Victoria 2010). Similarly in New Zealand, most decision-making processes regarding biosecurity are strongly driven by risk assessment procedures and protocols (e.g., Murray 2002, Hewitt et al. 2004, MAFBNZ 2006, Bell et al. 2011)

1.3 NEW ZEALAND MARINE BIOSECURITY

The term Biosecurity has been widely adopted internationally, but its use and interpretation varies between countries and agencies (e.g., Anderson 1998, Casagrande 2001, Hewitt and Hayes 2001, Beers et al. 2005, Hennessy 2008). The term appeared in the late 1980s but it was first used formally in New Zealand in the New Zealand Biosecurity Act (1993), which ironically does not define biosecurity. In 2000, the Parliamentary Commissioner for the Environment used previous definitions of biosecurity (e.g., MAF 1999, MoRST 1998) to describe it as 'the management of exotic biological risks that may harm New Zealand's economic, environmental and social interests.' Then the Biosecurity Strategy for New Zealand (Biosecurity Council 2003) defined biosecurity as 'the exclusion, eradication or effective management of risk posed by pests and diseases to the economy, environment and human health.' This definition is very similar to McNeely et al. (2001)'s but uses 'pests and diseases' instead of 'organisms'. Around this time, Meyerson and Reaser (2002) and Meyerson et al. (2002) also included protection against bioterrorism[3] under the biosecurity term.

In 2007 the Food and Agriculture Organization (FAO) described biosecurity as 'a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) for analysing and managing relevant risk to human, animal and plant life, and associated risks to the environment' (FAO 2007). More recently, aquatic biosecurity has been defined as 'national, regional, and international efforts to prevent, reduce and manage the introduction of pests, diseases or unwanted organisms via entry and border surveillance, short-term response and long-term control of established pests' (Dahlstrom et al. 2010).

The biosecurity system in New Zealand comprises three sequential, equally important and highly interactive sections: pre-border, border and post-border (MAFBNZ 2009, Acosta and White 2011). New Zealand terrestrial, aquatic and marine biosecurity operate similarly across this continuum to reduce the risk of NIS introduction, establishment and spread (MAFBNZ 2009). Pre-border biosecurity includes international agreements, import risk analysis, border standards and pest risk analysis. Border biosecurity includes pathway risk analysis, clearance standards and inspections. Post-border biosecurity includes response, response plans, management and surveillance programmes. The latter including passive surveillance (e.g., citizens reporting suspected pests within the country).

The eradication of introduced species is costly (Ruesink et al. 1995) and success is never guaranteed. Hence, prevention of NIS introductions is widely recognised as the most effective and cost-efficient management option (Mack et al. 2000, Rejmanek 2000, Leung et al. 2002, Simberloff 2003, Marchetti et al. 2004, Finnoff et al. 2007). Consistently, marine biosecurity has mainly focused on pre-border and border (i.e., national) management, ignoring to a large extent the importance of post-border (i.e., regional) spread or secondary introductions (Wasson et al. 2001, Hewitt et al. 2004). For example, while mid ocean ballast water exchange is a strict requirement for incoming vessels discharging ballast waters in New Zealand (MAFBNZ 2005), regional ballast waters (i.e., within the country) are not managed. Similarly, the new Biofouling Craft Management Risk Standard, scheduled to be released in mid 2013, will provide guidelines and empower authorities to improve biofouling risk management of vessels

[3] Defined by Meyerson and Reaser (2002) as the deliberate release of living organisms to inflict harm either directly or indirectly. A more comprehensive definition of bioterrorism states that it is 'the use, or threatened use, of biological agents to promote or spread fear to or intimidate an individual, a specific group, or the population as a whole for religious, political, ideological, financial or personal purposes' (Chomel and Sun 2010).

arriving in New Zealand. Although this standard could be applied to domestic vessels, there are no plans to date to implement it at this level.

Marine post-border biosecurity in New Zealand has largely been reactive (B. Gould, pers. comm.). While a series of baseline surveys at ports and marinas were conducted during the first decade of 2000 (e.g., Inglis 2001, Inglis et al. 2003, 2006a,b, Stuart et al. 2009), and an ongoing targeted surveillance programme is now in place (Inglis et al. 2006c, Acosta and White 2011), most previous management activities have been *ad-hoc* and related to responses (e.g., Gust et al. 2006a,b, 2008, Pannell and Coutts 2007, Jones et al. 2012). Only recently has proactive post-border management received interest and structured communication programmes and initiatives such as the Biosecurity Partnerships (MAF 2012) and the programmes Vessel Cleaning (MAF 2011a), Clean Marinas (www.cleanmarinas.org.nz) been developed.

The objective of the Biosecurity Partnerships initiative (e.g., Top of the South Marine Biosecurity Partnership, Top of the North marine Biosecurity Partnership, Fiordland Marine Biosecurity Partnership) is to create partnerships between central, regional and local government agencies and stakeholders from specific regions across New Zealand, enabling the development and implementation of effective and efficient regional marine biosecurity strategies (MAF 2012). Clean Marinas and Vessel Cleaning, designed for marina operators, boatyards, contractors and individual recreational vessel users, are programmes that although not solely biosecurity oriented, promote sustainable environmental initiatives and encourages 'environmentally sound Best Management Practices.' Similarly, research into the dynamics and potential management of domestic vectors and pathways, as well as on the biology, ecology, and control and eradication options of marine pests currently present in New Zealand is also becoming a priority (see Table 1.2 for examples).

The most recent initiative is the Marine Pathways Project (Inglis et al. 2012b) aimed at engaging industry, government, *tangata whenua*, councils and other stakeholders (e.g., research institutes) to define a recommended set of measures for domestic pathways. The project targets the following pathways:

1. maritime transport,
2. mining and exploration,
3. commercial fishing,
4. marine aquaculture,
5. sport and recreation, and
6. research and education.

At the time of writing, a series of workshops is underway involving experts on marine invasions, pathways and risk assessment, from both governmental (central, regional, and local) and non-governmental (e.g., universities, research institutes) agencies, and industry representatives.

Table 1.2 Examples of New Zealand post-border research and management initiatives. Note this is an indicative but incomplete list of initiatives within New Zealand.

Title	Reference
▪ANZECC Code of Practice for Antifouling and In-Water Hull Cleaning and Maintenance	Marcus and Baker 1997
▪Investigation of Vector Management Techniques to Reduce the Spread of *Undaria pinnatifida* in New Zealand	McClary and Stuart 2004
▪Human-mediated pathways of spread for non-indigenous marine species in New Zealand	Dodgshun et al. 2007
▪Treatment methods used to manage *Didemnum vexillum*	Pannell and Coutts 2007
▪Assessment of population management options for *Styela clava*	Gust et al. 2008
▪Evaluation of marine response tools: Subtidal containment and treatment system	Stuart et al. 2008
▪Vessel movements within New Zealand	Hayden et al. 2009
▪Pest Management National Plan of Action	MAF 2011b
▪Biology and ecology of the introduced ascidian *Eudistoma elongatum*, and trials of potential control options	Morrisey et al. 2009
▪Options for managing biosecurity risks from recreational vessel hubs	Piola and Forrest 2009
▪Fiordland Marine Biosecurity Risk Management: Operational Plan Recommendations 2009/10–2013/14	Sinner et al. 2009
▪Top of the South Operational Plan	The Lawless Edge Ltd. 2009
▪Slowing Pest Spread - Domestic Pathways of Human Mediated Pest Spread and Opportunities for their Management	Biodiverse Limited 2010
▪Development of a Template for Vessel Hull Inspections and Assessment of Biosecurity Risks to the Kermadec and sub-Antartic Island Regions	Floerl et al. 2010a
▪Proposed Regional Coastal Plan–Kermadec and Subantarctic Islands	DoC 2011
▪Risk Analysis: Vessel Biofouling	Bell et al. 2011
▪Draft Antifouling and In-water Cleaning Guidelines	MAF 2011c
▪Aquaculture readiness database Phase II	Morrisey et al. 2011
▪Scenarios of Vessel Biofouling Risk and their Management	Inglis et al. 2012a
▪Clean boats–Living seas	MAF 2011d

Despite increased awareness of domestic marine NIS pathways and vectors, and the need for a specific legislative regime to manage marine pests in New Zealand

(Allen+Clark 2012)[4], there are no specific regulations or management plans addressing them (M. Russell, pers. comm.). Similarly, our knowledge of these pathways and associated vectors, essential for such biosecurity management, is still limited; even in regions such as Golden Bay and Tasman Bay where the Top of the South Marine Biosecurity Partnership has been implemented since 2009 (The Lawless Edge Ltd 2009).

1.4 GOLDEN BAY AND TASMAN BAY–VALUES AND BIOSECURITY

Golden Bay and Tasman Bay are two relatively large, shallow neighbouring embayments at the top of the South Island, New Zealand (Fig. 1.2). Tasman Bay is approximate 75 km wide and delimited on the east by D'Urville Island and on the west by Separation Point. Golden Bay has a semicircular shape that extends from Separation Point to Farewell Spit. The seabed in both bays is mainly within the 50 m bathymetric contour and characterised by low gradients, usually 1:1000 (Mitchell 1986). There are localised areas of submerged rocks and shoaling, generally within the 10 m deep and 1–4 km of the coast (Hydrographic Office 1984, 1989).

Except for Farewell Spit (a 32 km long, 1 km wide sand barrier), the seafloor in Golden and Tasman Bays is mostly formed by mud and sandy mud, with isolated areas of calcareous gravel (Mitchell 1987, Keeley et al. 2006). Mean circulation is asymmetric and circular. While in Golden Bay the mean flow is clockwise and stronger along Farewell Spit, in Tasman Bay it is predominantly anticlockwise with stronger flows near D'Urville Island (Heath 1974, 1976, Tuckey et al. 2006). Both bays have a range of environments that include coastal tidal wetlands, estuaries, harbours, inlets, intertidal flats, and partially enclosed bays.

Several studies have recorded a wide range of infaunal and epifaunal organisms in subtidal and intertidal areas across Golden Bay and Tasman Bay (e.g., Bradstock and Gordon 1983, Gillespie and MacKenzie 1999, Handley et al. 1999, Grange 1998, Grange and Cole 1999, Grange et al. 2001, Davey et al. 2004, Battley et al. 2005, Morrisey et al. 2005a,b, Inglis et al. 2006a,b, Stuart et al. 2009). The benthos in these bays is mainly soft-bottom fauna, with bivalves and echinoderms being the predominant groups (Cole et al. 2003, Keeley et al. 2006). There are areas off Abel Tasman National Park and D'Urville Island (Fig. 1.1) with large populations of Bryozoa (some forming coralline growths or 'reefs') (Broadstock and Gordon 1983). These habitats are considered to be nursery grounds for snapper (*Chrysophrys auratus*), tarakihi (*Nemadactylus macropterus*), and John Dory (*Zeus faber*) (Vooren 1975, Saxton 1980).

The region encompasses coastal and marine areas highly valued because of their environmental, socio-cultural, economic and Māori significance. There are several sites across Golden Bay and Tasman Bay considered regionally and nationally important (Davidson et al.

[4] Marine biosecurity management regime in New Zealand is mainly regulated by the Biosecurity Act 1993 (modified by the Biosecurity Law Reform Bill 2012), the Resource Management Act 1991 and the New Zealand coastal Policy Statement 2010. Other legislation and regulations relevant to the management of MNIS include the Maritime Transport Act 1994, the Resource Management (Marine Pollution) Regulations 1998, the Local Government Act 2002, the Draft Anti-fouling and In-water Cleaning Guidelines (MAF 2011c), and the Import Health Standard for Ships' Ballast Water from all countries (MAFBNZ 2005), among others (Allen+Clark 2012).

1993). Farewell Spit, with sandspit dunes and vast intertidal flats covered by extensive seagrass (*Zostera muelleri*) beds, has been designated by under the Ramsar Convention[5] as a 'Wetland of International Importance' (Molloy 1994) (Fig. 1.2). Similarly, Nelson Boulderbank (in Nelson) and Back Beach (in the Waimea Inlet) are considered of international importance (Davidson and Preece 1994).

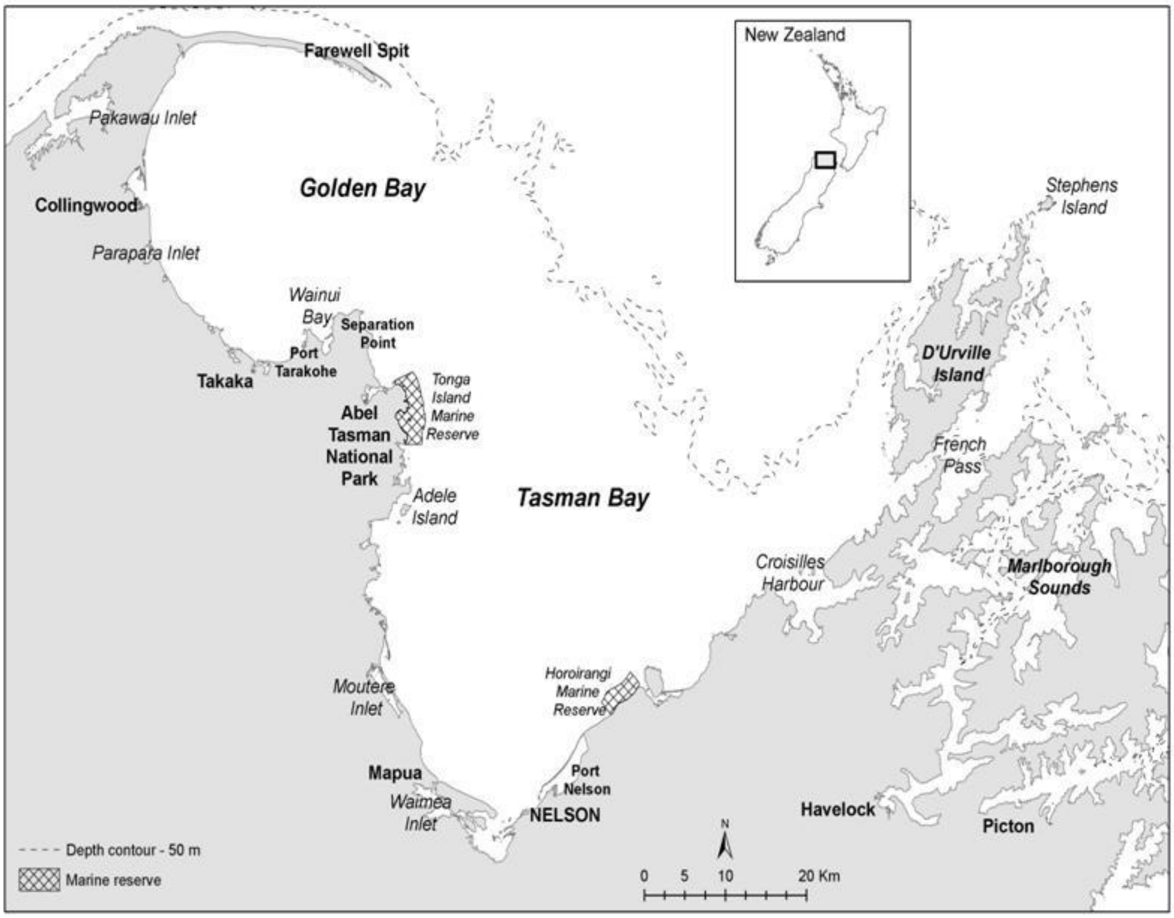

Figure 1.2 Golden Bay and Tasman Bay, at the top of the South Island, New Zealand.

Estuaries across the region, especially in Farewell Spit and the Abel Tasman National Park, are important for indigenous shorebirds species as wintering areas but may be also important to other migratory birds (Schuckard 2002, Dowding and Moore 2006). Tasman Bay includes the Tonga Island Marine Reserve and the Horoirangi Marine Reserve. It also contains Waimea Estuary, which apart from supporting a diversity of macroinvertebrates, fish and bird life (Davidson and Moffat 1990), is New Zealand's largest estuary. Areas within Tasman Bay are also important breeding sites for local seal populations (TDC–DoC 2012).

Golden Bay and Tasman Bay host several growing, collecting, and enhancement sites for commercially important shellfish species such as the southern scallop *Pecten*

[5] This is the common name used to refer to the Convention on Wetlands of International Importance, an intergovernmental treaty adopted in Ramsar, Iran in 1971 that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

novaezelandiae, the Pacific oyster, and New Zealand Greenshell™ Mussel[6] *Perna canaliculus*. Aquaculture involving mussels has been intensely developed throughout this region, making Golden Bay and Tasman Bay important farming areas for this nationally and internationally marketed species (Aquaculture New Zealand 2012). The bays also support valuable recreational fisheries for the Bluff (dredge) oyster (*Tiostrea chilensis*) and snapper (Davidson and Preece 1994).

The coast of the Abel Tasman National Park is a national and international icon that: 1) attracts thousands of both domestic and international tourists, 2) makes a significant contribution to the economy of the region, and 3) helps market the country as a worldwide tourism destination (TDC–DoC 2012). The natural features of these coastlines contribute to New Zealand's international reputation as a country with outstanding natural values (TDC–DoC 2012).

Archaeological evidence of middens, kumara storage pits, hut terraces and defensive ditches reveals much about previous Māori occupation in both Golden Bay and Tasman Bay (Dennis 1985). Many estuaries here were used by Māori as food gathering areas, and some are still considered important source of *kaimoana,* especially Marahua Beach, Tapu Bay, and Motueka Beach (TDC–DoC 2012). Other areas such as Delaware Bay (*Whakapuake*) are regarded as *Taiapure* and have special significance for Māori (www.nabis.co.nz). The coastal wetlands are also an important part of the natural heritage of this region with many plants and animals area endemic (e.g., de Lange et al. 2009).

This area is also an important transport hub. Port Nelson, at the southern end of Tasman Bay, is Australasia's largest shipping port (www.portnelson.com.nz) and home to several cargo and fishing vessel fleets such as *Amalta* and the *Sealord Group*. It is also the first port of call for international commercial and recreational vessels from Australia, Japan and the Pacific Islands among other countries and handles high volume of national shipping traffic (Inglis et al. 2006b, Morrisey and Miller 2008, Hayden et al. 2009, Port Nelson 2012). For the last few years Port Nelson has produced an annual revenue of ca. NZ$ 38 million (Port Nelson 2012). Port Tarakohe in Golden Bay is comparatively smaller and used by a range of crafts such as recreational vessels, aquaculture servicing vessels and barges, cruise liners, and small bulk carriers (Hayden et al. 2009, Stuart et al. 2009, Morrisey 2010).

1.4.1 Marine NIS, vectors and biosecurity in Golden Bay and Tasman Bay

As with most regions across New Zealand (Cranfield et al. 1998, www.marinebiosecurity.org.nz) Golden Bay and Tasman Bay have a history of marine NIS. To date, there have been at least 47 marine NIS species recorded in the wild within these bays and 19 observed as biofouling of resident or visiting vessels (Tables 1.3 and 1.4). Among these are some well-established high profile pest species (e.g., the tunicates *Ciona intestinalis* and *Didemnum vexillum*, and *U. pinnatifida*) that threaten some of the values and resources of the region such as aquaculture (Sinner et al. 2000, Forrest et al. 2000, Sinner and Coutts 2003,

[6] The correct common name for this species is 'Green-lipped mussel' but the aquaculture industry markets it under the registered trademark 'New Zealand Greenshell™ Mussel'.

Coutts and Forrest 2007). Management of other high profile species includes the invasive *Spartina* cordgrass, now successfully eradicated from most of the region, after it reached dense populations across more than 30 hectares in the Waimea Estuary (Nelson City Council 2003). Also, the tunicate *Styela clava* has been detected on several occasions in this region but is not considered to be established (Morrisey et al. 2006, Morrisey and Miller 2008).

Marine NIS may arrive in this region directly from overseas or via domestic spread (natural or human-mediated). Commercial shipping and fishing, as well as aquaculture, appear to be the main pathways for introduction and further spread of marine NIS in Golden Bay and Tasman Bay (e.g., Inglis et al. 2006a,b, Dodgshun et al. 2007, Coutts et al. 2007, Morrisey and Miller 2008, Floerl et al. 2009, Hayden et al. 2009). Port Nelson is the main shipping hub for the South Island (Morrisey and Miller 2008, Hayden et al. 2009). Since 2007 it has annually traded between 2.65–2.76 million tonnes of cargo and received between 733–921 vessels (>100GT) (Port Nelson 2012). Between 2004–2006, visiting and local vessels connected Port Nelson with 17 ports across the North Island and South Island (Morrisey and Miller 2008, Hayden et al. 2009). In addition to commercial shipping, fishing and aquaculture, recreational boating is also considered an important marine NIS pathway in Golden Bay and Tasman Bay (McClary and Stuart 2004, Floerl et al. 2009, Hayden et al. 2009, Lacoursière-Roussel et al. 2012).

Ballast water and biofouling of other vessels and towed structures such as tugs, dredges, and oil rigs can be important introduction vectors. This was clearly demonstrated in 2007 when the defouling of an oil rig introduced the NIS brown mussel *Perna perna* to Tasman Bay, leading to a dredge-based incursion response (Hopkins et al. 2011). Other mechanisms such as the marine aquarium trade, live seafood, and public aquaria, although not investigated to date, may create pathways for marine NIS in this region (e.g., Smith et al. 2010b). Natural currents may also transport NIS into and around the region. For example, the bryozoa *Electra tenella*, present in Tasman Bay, is believed to have arrived in New Zealand attached to drifting plastic (Cranfield et al. 1998).

Table 1.3 List of NIS reported for Golden Bay and Tasman Bay. Potential vector for spread indicated. H=Hull fouling, B=Ballast water, A=Aquaculture, PD=Plastic drifting, C=Currents. *=Observed as biofouling on the hull of vessels within the region. *†*=Previously described as *Electra tenella. Φ*=Eradicated. 1=Partridge 1987, 2=Roberts 1992, 3=Forrest and Roberts 1995, 4= Stevens 1997, 5=Barter 1999, 6=Hopkins 2001, 7=Cole et al. 2003, 8=Grange et al. 2003, 9=Grange and Gordon 2005, 10=Bennett et al. 2006, 11=Davidson and Richardson 2006, 12=Handley 2006, 13=Inglis et al. 2006b, 14=Keeley et al. 2006, 15=Morrisey et al. 2007, 16=Pannell and Coutts 2007, 17=Asher et al. 2008, 18=James 2008, 19=Morrisey et al. 2009, 20=Robertson and Stevens 2009, 21=Stuart et al. 2009, 22=Morrisey 2010, 23=Smith et al. 2010a, 24=Hopkins et al. 2011, 25=Woods and Inglis 2011, 26=www.marinebiosecurity.org.nz, 27=www.nzpcn.org.nz, 28= Data provided by Marine Invasives Taxonomic Service in 2012.

Location	Vector	Species	Reference
Port Nelson		*Anguinella palmata*	28
Nelson		*Amphibalanus amphirite*	28
Nelson		*Apocorophium acutum**	28
Nelson		*Arenigobius bifrenatus*	28
Nelson		*Aspidelectra zhousanica*	28
Tarakohe		*Barantolla lepte*	21
Golden Bay		*Biflustra grandicella*	9, 12, 13

Location	Vector	Species	Reference
Collingwood, Port Nelson, Tarakohe, Wainui	H-A	*Bugula flabellata*	13, 21
Tarakohe		*Bugula neritina*	21
Nelson		*Bugula simplex*	28
Tarakohe, Port Nelson	H	*Celleporaria nodulosa*	13, 22
Nelson		*Celleporaria pilaefera*	28
Nelson marina		*Clavelina lepadiformis*	25
Port Nelson	H	*Ciona intestinalis*	13, 15
Port Nelson		*Ciona savigny*	23
Port Nelson		*Cnemidocarpa stolonifera*	13, 28
Port Nelson	H	*Conopeum seurati*	13
Nelson, Moutere, Motueka, Motupipi, Ruataniwha, Tarakohe, Waimea, Whanganui	H	*Crassostrea gigas**	3, 5, 10, 13, 17, 20, 21
Nelson, Tarakohe	H	*Cryptosula pallasiana*	13, 21
Nelson		*Cyclicopora longipora*	28
Nelson		*Didemnum sp.*	11, 16, 28
Port Tarakohe, Tonga Island, Horairangi Marine Reserve		*Didemnum vexillum*	7, 8, 11, 16, 22
Port Nelson	H-PD	*Electra angulata*†	13
Nelson		*Electra belulla*	28
Parapara Inlet		*Eudistoma elongatum*	19
Port Nelson	H	*Filellum serpens*	13
Nelson marina		*Grateloupia turuturu*	25, 28
Nelson, Motueka		*Haliplanella lineate*	13
Port Nelson	H-B	*Hydroides elegans**	13, 15
Port Nelson	H-B	*Lafoeina amirantensis*	13
Separation point	C	*Limaria orientalis*	8, 12, 21, 25
Tasman Bay	H	*Perna perna*ɸ	24
Port Nelson	H-A	*Polydora hoplura*	13
Waimea		*Punctaria latifolia*	17
Nelson		*Savignyella lafontii*	28
Port Nelson	H	*Schizoporella errata*	13
Nelson		*Scrupocellaria cf. diadema**	28
Waimea		*Spartina anglica*	1, 18, 20
Nelson, Tarakohe		*Styela clava**	15, 22
Port Nelson		*Styela canopus*	25
Port Nelson	H	*Synthecium campylocarpum*	13
Nelson, Golden Bay, Waimea, Monaco	B-C	*Theora lubrica*	2, 5, 6, 10, 13, 14, 17, 21, 22
Tarakohe		*Tricellaria catalinensis*	21
Waimea		*Ulva lactuca*	17,10
Collingwood, Nelson, Mapua, Monaco, Tarakohe, Wainui	A-H-B	*Undaria pinnatifida**	4, 13, 17, 18, 21, 22, 26
Collingwood, Nelson, Wainui, Tarakohe	H-B	*Watersipora subtorquata**	10, 13, 21
Waimea		*Wilsonia backhousei*	27

(Table 1.3 continued)

Table 1.4 NIS observed as biofouling on the hull of resident or visiting vessels within Golden Bay and Tasman Bay. Data provided in October, 2012 by the Marine Invasives Taxonomic Service of New Zealand.

NIS as hull fouling within Golden Bay and Tasman Bay		
-Amphibalanus improvisus	*-Ectopleura crocea*	*-Megabalanus peninsularis*
-Amphibalanus reticulatus	*-Ficopomatus enigmaticus*	*-Nevianipora pulcherrima*
-Amphibalanus venustus	*-Jassa marmorata*	*-Pyura elongata*
-Brettiella culmosa	*-Jassa slatteryi*	*-Scrupocellaria bertholletii*
-Caprella californica	*-Laticorophium baconi*	*-Tricellaria catalinensis*
-Celleporaria inaudita	*-Lepas anserifera*	
-Celleporaria sibogae	*-Megabalanus coccopoma*	

1.5 THE THESIS

The objective of this thesis is to present baseline information and concepts developed for the analysis and potential management of three NIS pathways:

1. recreational boating,
2. aquaculture, and
3. natural currents.

These pathways have been selected because they are common and important throughout the world. They also represent feasible (recreational boating and aquaculture) and unrealistic (natural currents) management scenarios.

The methodologies presented are generic. They have been conceived and developed in such a way that they can be readily applied across other pathways and different regions. Their implementation is demonstrated using Golden Bay and Tasman Bay as a case study (Fig. 1.2). The case-study region was selected because it is highly valued for its conservation, economic, social and cultural resources and because it has a history of these values being threatened by marine NIS incursions.

Chapter 2 presents a comprehensive conceptual model identifying the sequence of events that could lead to a species invasion via recreational vessels. The model is developed using the fault tree analysis technique and uses input from a group of national and international experts. Chapter 3 draws on the model presented in Chapter 2 and uses expert opinion on the characteristics of recreational boating to assess the likelihood of NIS invasions in different marine facilities visited by recreational vessels. Fuzzy logic is used to integrate expert likelihood estimates. Estimates are combined with a connectivity parameter using a prioritisation number to define management priorities across the region. The connectivity parameter used reflects the number and type of marine structures associated with recreational boating in a particular area, as well as cruising routes and usage frequency.

Chapter 4 is devoted to the analysis of aquaculture as a regional pathway for NIS. Using farming of the New Zealand Greenshell™ Mussel in Golden Bay and Tasman Bay as a model, it identifies components, processes and potential vectors for the spread of NIS. It also identifies interactions between this pathway and other potential spread mechanisms such as recreational boating, public aquaria, and research. In Chapter 5 an advection-diffusion model is developed to investigate the role of natural coastal currents in the regional spread of NIS. The effect of the propagule release location and planktonic propagule duration on dispersal and connectivity patterns is also explored.

The final chapter summarises the main concepts presented in previous chapters. It contains an integrated assessment of recreational boating, aquaculture, and natural currents in the case-study region that demonstrates the importance of considering regional pathways as an integral network for the spread of marine NIS rather than as isolated systems. Possible applications for the information and concepts presented are also suggested.

Chapter 2: A conceptual model for the release of non-indigenous species from recreational vessels

2.1 INTRODUCTION

Vessel traffic is recognised as being a particularly important vector for invasions, and many studies have described the role played by commercial shipping in the spread of NIS, especially via ballast water, external fouling and sea chests (Carlton 1985, Ruiz et al. 1997, 2000, Hewitt et al. 1999, Coutts and Taylor 2004, Coutts and Dodgshun 2007, DiBiacco 2011, Keller et al. 2011). Nonetheless, other pathways can also be important contributors to invasions (Naylor et al. 2001, Wasson et al. 2001, Chapman et al. 2003, Weigle et al. 2005, Coutts and Dodgshun 2007, Hulme et al. 2008). Within this pathway, the role of recreational boating is increasingly highlighted for its involvement in the post-border domestic spread of marine NIS (Fletcher and Farrell 1998, Lambert and Lambert 1998, Hewitt and Campbell 2001, Hutchings et al. 2002, Floerl and Inglis 2003, Floerl et al. 2005a, Minchin et al. 2005, Ashton et al. 2006a, Goldstien et al. 2010, Clarke Murray et al. 2011).

Most of our understanding of the risk of marine invasions via recreational vessels relates to hull fouling (e.g., Floerl et al. 2005a, Ashton et al. 2006a, Floerl et al. 2009, Clarke Murray et al. 2011, Hewitt et al. 2011, Lacoursière-Roussel et al. 2012). Conversely, the role of recreational boats in the spread of freshwater NIS has been researched for more than three decades, and a range of mechanisms have been described in addition to hull fouling alone (Johnstone et al. 1985, Buchan and Padilla 1999, Bossenbroek et al. 2001, Johnson et al. 2001, Pollux et al. 2003, MacIsaac et al. 2004, Boltovskoy et al. 2006).

In the marine environment, only one published study (Hayes 2002a) has characterised recreational vessels into different components (e.g., hull, deck, internal spaces). Hayes (2002a) evaluated the relative importance of recreational vessel components based on their potential to entrain and transport NIS. However, to date, there has been no comprehensive assessment describing the complexity of recreational boating as a pathway in the marine invasion process. Risk-based approaches provide one means of considering such issues.

Traditional ecological risk assessment (ERA) provides a process for evaluating the likelihood and consequences of adverse ecological effects as a result of exposure to one or more stressors (Gentile et al. 1993, Suter et al. 1993). More recently, ERA has been suggested to be a useful method for identifying, prioritising and managing marine bioinvasion risks (Hayes 1997, Hewitt and Hayes 2002, Landis 2003, Forrest et al. 2006, Leung and Dudgeon 2008, Campbell 2009). The effectiveness of ERA relies on a systematic approach to identify relevant hazards of a system that could lead to unwanted consequences (Glossop et al. 2000). Thus, special attention must be given to the hazard identification part of the ERA, since omitting hazards in the early stages of the process may reduce the objectivity of the assessment (Hayes 2002b). Fault tree analysis is a common technique used in engineering to formalise conceptual models (Burgman 2005, Ostrom and Wilhelmsen 2012). This is a structured and systematic approach whose efficacy as a hazard identification tool has been demonstrated in many engineering studies (Andrews and Moss 2002). Similarly, its potential to analyse marine invasion pathways was shown when this approach was applied to ballast water introductions (Hayes 1998, Hayes and Hewitt 1998, Hayes 2002b).

This chapter presents a conceptual model for the marine invasion process via recreational vessels. The model characterises this invasion vector using the logic and techniques of fault tree analysis. However, this work was not intended to be a quantitative risk assessment or a fault tree analysis in its strictest sense.

As with any invasion, NIS marine invasions via recreational boating can be described as a multi-step process that includes: 1) uptake from native range, 2) transfer via vector (i.e., recreational vessels), 3) arrival/release, 4) establishment, and 5) population increase and range expansion (Lockwood et al. 2005). A comprehensive model covering all these steps would be complex and convoluted. Therefore, for simplicity, the model development here focuses on the release phase of the invasion process (i.e., the release of NIS from an infected vessel into a new area), primarily to demonstrate the merits of the fault tree approach. While there are references to transport and post-release factors that may affect the likelihood of pest establishment and range expansion in a recipient locality, these phases of the invasion process are not discussed in any detail.

By considering only one step of the invasion process via recreational vessels, the applicability of the model is certainly reduced. However, it is important to recognise that management measures at any point along the continuum between steps 1–3 could decrease the likelihood of NIS spread between regions. The effectiveness of such management is still dependent on our clear understanding of each step of the process, which often is only possible through models such as the one presented here.

2.2 METHODS

2.2.1 Fault tree analysis

Fault tree analysis graphically analyses a system from top to bottom, identifying the occurrence of an event (the top event) as the result of the occurrence or non-occurrence of other (intermediate) events (Barlow and Lambert 1975, Henley and Kumamoto 1981, Bedford and Cooke 2001). Intermediate events also are described further until the basic or undeveloped events are identified. Basic events require no further development because an appropriate level of resolution has been reached. Undeveloped events require no further development because information is unavailable or because their consequences are insignificant. Using the logic functions OR and AND, a fault tree represents graphically all the parallel and sequential combinations of events that could make the top event occur (Vesely et al. 1981, Andrews and Moss 2002). A list of the symbols commonly used in fault tree analysis is provided in Figure 2.1. Intermediate events have only one input, which can be a basic event, an undeveloped event or a logic gate (OR or AND). Logic gates can have any number of inputs. These inputs can be intermediate, basic events and/or undeveloped events. The resulting event of an OR gate occurs if one or more of the inputs occur. The resulting event of an AND gate occurs only if all the input events occur (see Appendix A for an example).

Model development followed a Delphi approach (e.g., Delbecq et al. 1975, Rohrbaugh 1979) and incorporated input from two panels of experts to ensure an accurate representation and comprehensive breakdown of vessel risk components. The Delphi method is a unique approach for eliciting and refining group expert judgement, which structures the communication process within the group allowing individuals to deal with a complex problem, and when possible to reach a consensus (Linstone and Turof 1975, Richery et al. 1985). This technique requires experts to answer questionnaires in two or more rounds. After each round the researcher provides an anonymous summary of suggestions from the previous round. The researcher stops the process when the results have reached the desired level of stability (Richery et al. 1985).

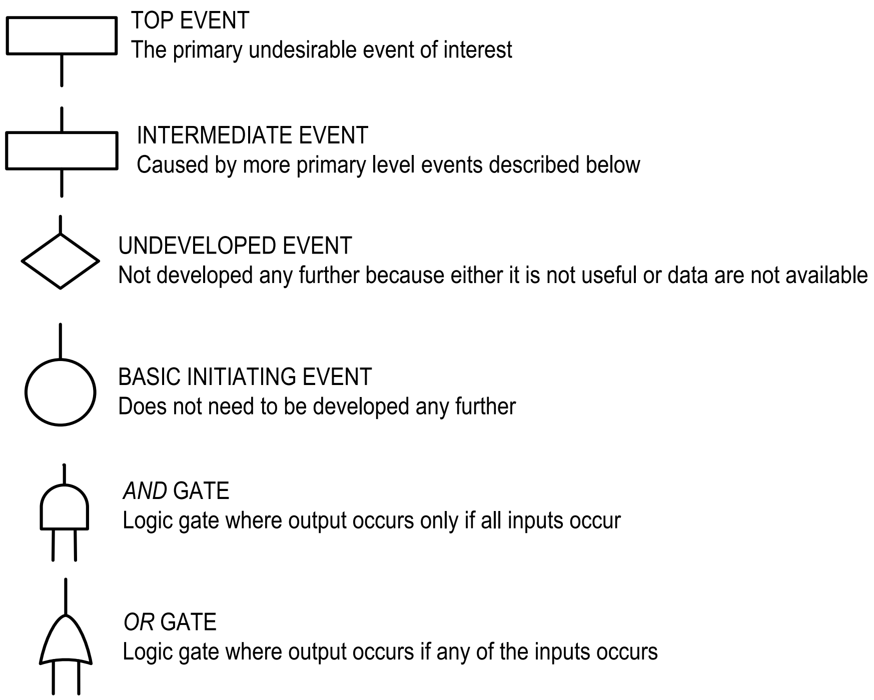

Figure 2.1 Commonly used symbols in Fault Tree Analysis (Vesely et al. 1981).

2.2.2 Development of a conceptual model

Using the vessel components and infection modes (i.e., ways in which the components can be infected with NIS) identified by Hayes (2002a) and following the fault tree analysis technique, the marine invasion process via recreational moored and trailered vessels was formulated. A total of five vessel components (i.e., Hull, Deck, Internal spaces, Anchor and Fishing gear) and three infection modes (i.e., water/sediment retention, fouling and refuge) were considered (Table 2.1).

To date, it is widely recognised that the probability of developing biofouling is not the same across the hull area of vessels (e.g., Lewis 2002, Floerl et al. 2005a, ASA 2007, Department of Fisheries 2009, IMO 2011). There are some particular areas ('niche areas') such as the keel and stabilisers, propeller and shafts, rudder and casings and transducers, which among others are more susceptible to biofouling due to different hydrodynamic forces, susceptibility to cleaning and antifouling wear, and/or being inadequately painted (Floerl et al. 2005a, Davidson et al. 2010, Hopkins and Forrest 2010b, Clarke Murray et al. 2011). Nevertheless, the present study considered that including each of these parts as separate components in the analysis would make the exercise ‘very vessel-specific’ and extremely time consuming, and could potentially generate (unnecessary) redundancy. Hence, as with Hayes (2002a), for simplicity the present study considered all parts below the water line (including propeller and rudder) as the single component Hull.

Table 2.1 Vessel components and infection modes (modified from Hayes 2002a). Infection modes used in the first exercise (initial model) and following exercises (final model). ** The component Trailer was not included in the first exercise

Vessel component	Infection modes		Examples
	Initial model	Final model	
Hull, propeller and rudder (Hull)	Fouling Refuge	Fouling	Propeller surfaces
Deck	W/S retention Fouling	W/S retention Fouling	Hawser pipe Cracks between plates
Internal spaces (including ballast tanks)	W/S retention Fouling Refuge	W/S retention Fouling	Bilge Seawater inlet/outlet
Anchor	W/S retention Fouling	W/S retention Fouling	Rope Anchor surface
Fishing gear (including diving gear)	W/S retention Fouling Refuge	W/S retention Fouling	Trap ropes Dredges
Trailer	**	W/S retention Fouling	Hollow section of chassis Mudguards

The infection mode water/sediment retention referred to any water or sediment retained in any component even when the vessel was out of the water (Hayes 2002a). Fouling referred to sessile organisms attached to a surface and refuge to a place on the vessel that could be used by mobile organisms as habitat (Hayes 2002a). Fouling also covered entanglement of organisms or propagules.

The events that could lead to release of NIS from an infected vessel into a new area (the release phase) were identified as a series of fault trees. All fault trees were integrated into an initial conceptual model. The events incorporated into the model were based on personal observations, and informal conversations with recreational boat owners from the marinas of the Outboard Boating Club (Auckland), Port Tarakohe (Golden Bay) and Port Nelson (Tasman Bay), as well as boat ramps in Abel Tasman National Park (Tasman Bay). This reflects a range of recreational vessel types (e.g., barges, keelers, trailer boats) and activities (e.g., cruising, recreational fishing, diving, racing) common to many regions across New Zealand.

2.2.3 Refinement of conceptual model using a panel of experts

To refine the conceptual model two sets of elicitation exercises were conducted with two panels of experts. The first set was conducted between October 2005 and April 2006, and for this, the author contacted 27 people (personally or via email) with a formal invitation to participate as a member of a panel of experts (Appendix A.1). These people were selected by the author as potential participating 'experts' because he knew they worked (or had worked) and/or have peer-reviewed publications in at least one of the following fields: invasion biology, marine biology, recreational boating, risk assessment or biosecurity. In order to ensure independence among experts, they were selected from different governmental and non-governmental environmental agencies from New Zealand and overseas (Ayyub 2001). The invitation stated that the objective of the panel was to gather expert opinion to help modelling recreational boating as a pathway for NIS. It also stated that the information provided by experts of the panel would be anonymous and only used for the purpose of the research, which had no commercial purpose (Appendix A.1).

A formal elicitation exercise was then emailed to all the experts that agreed to participate (Appendix A.1). The exercise comprised a cover letter and two main sections. The cover letter presented the objectives of the exercise and a brief description of the methodology used. The first section of the survey gave baseline information on marine NIS, recreational boating as a pathway for NIS, and the fault tree analysis technique. This ensured that all the experts had a minimum common knowledge (Ayyub 2001). The second section explained the initial conceptual model and the procedure followed to create it. In order to reduce linguistic uncertainty generated by ambiguity and underspecificity (Regan et al. 2002, Burgman 2005), this section included all the assumptions and definitions used in the model. Similarly, in order to minimise linguistic uncertainty generated by context dependence (Burgman 2005, Bedford et al. 2006), a specific scenario was given (i.e., 'Vessel V, a recreational vessel, travels from Area Y to Area Z'. Species S is present in Area Y, but it has never been present in Area Z').

Experts were asked to analyse the model and make any changes they considered necessary in order to have a comprehensive and accurate conceptual model for analysing marine bioinvasion risks from recreational vessels. Based on feedback from the experts, the model was modified and sent back to them as part of the baseline information of a second elicitation exercise. The objective of this exercise (not discussed here) was to assess the probability of NIS introduction at different marine structures (e.g., marinas, boat ramps) via recreational vessels. Experts were asked to review the model before completing this second exercise. New comments and suggestions were subsequently included in the model. The revised model was then presented to a further six marine scientists and five recreational vessel owners, who suggested additional changes (mainly to its layout). The final version of the model was published as Acosta and Forrest (2009).

The second set of elicitation exercises was conducted between November, 2010 and June, 2011, using the same methods described for the first set of exercises (approved by the Auckland University of Technology Ethical Committee, Reference AUTEC 10/224). The author invited 20 people (personally or by email) to become members of the panel of experts, following the same selection criteria described above (Appendix A.2). People that had previously participated were not considered this time.

The first exercise included the published model (Acosta and Forrest 2009) with modifications based on feedback from two scientists with experience in invasion biology, biosecurity and risk assessment and management (Appendix A.2). This model also included the component Trailer, omitted in previous exercises (Table 2.1). Experts were asked to review this model and make any required changes. Based on their feedback, the model was updated and sent back to them as part of a second exercise (Appendix A.3). Their new feedback was included and the final version of the model is presented here. All exercises sent to both panels of experts were tested on between 3–5 people to make sure there the information was presented clearly and there was no ambiguity in the questions (Meyer and Booker 1991, Ayyub 2001).

2.3 RESULTS

2.3.1 Elicitation exercises

First set

Only 10 of the 27 people contacted agreed to be part of the group of experts and completed the first exercise. This group was comprised of seven experts working in New Zealand and three overseas (Table 2.2). The second exercise was only completed by six experts. The analysis of the model during the first set of exercises generated two main changes. First, the infection mode refuge was considered to be covered by fouling. Thus, both infection modes were unified under the latter for all components (Table 2.1). Second, 'spawning' was changed to 'releasing propagules', since this was more encompassing of all marine organisms included.

Second set

Only 14 out of the 23 people contacted agreed to be in the second panel of experts and completed the first exercise. This new panel was comprised of 11 people working in New Zealand and three from overseas (Table 2.3). Only six of the experts completed the second exercise. As a result of these exercises, the main modification to the model was including the event 'Accident' for all the vessel components (see section 2.3.2).

2.3.2 The model

The final model represents the introduction of species S (a NIS present in Area Y, but not in Area Z), when Vessel V (a recreational vessel) visits Area Z from Area Y. Although it includes the arrival and survival of Species S in Area Z, it focuses on the release process (Fig. 2.2). The final model included six vessel components and two infection modes (Table 2.1). All events in the figures have been numbered based on their citation in the text. This means that an event is referenced by the number of the figure and the number of the event in that figure. For example, 'release of propagules (3.2)' refers to the event number 2 in Figure 2.3. Similarly, 'Vessel V visits Area Y (2.14)' means that this is the event number 14 in Figure 2.2.

Table 2.2 Expert Panel 1–Expert background. NZ Cgov.= New Zealand Central government agency, NZ Lgov.= New Zealand Local government agency, O. R.agency= Overseas research agency, P= Doctor of Philosophy, M= Master of Science, H= High School Diploma, ϕ= Based on reports/publications or previous knowledge the author assumed the expert had experience in that field, but this information was not corroborated by the expert.

	Expert									
	1	2	3	4	5	6	7	8	9	10
Country/Region										
Australia	X									
Europe							X			
New Zealand		X		X	X	X		X	X	X
North America			X							
Current work place										
NZ Cgov.–A									X	
NZ Cgov.–B										X
NZ Lgov.						X				
NZ R.agency–A		X						X		
NZ R.agency–B				X						
NZ R.agency–C					X					
O. R.agency–A	X									
O. R.agency–B			X							
O. R.agency–C							X			
Field of experience (years)										
Marine Biology	ϕ	15	17	11	5		14	9	ϕ	ϕ
Marine Invasions	ϕ	5	15	7	2	9	13	9	ϕ	ϕ
Freshwater Invasions					1	15				ϕ
Terrestrial Invasions						15				ϕ
Statistics	ϕ				5					
Risk Assessment	ϕ	1		3			6	9	ϕ	
Recreational vessels	ϕ	10		7	5	40		5		
Highest education degree	P	M	M	P	P	H	P	M	P	P
Exercises completed	1	2	1	2	2	2	1	2	1	1

From Figure 2.2, it is evident that in order for ‘Area Z to become infected with Species S’ (2.1), which is the top event of the analysis, all the following three events must occur: Species S arrives in Area Z (2.2); AND Species S is released into Area Z (2.3); AND Species S survives in Area Z (2.4). The results below describe the steps required for these three events to occur.

2.3.2.1 Species S arrives in Area Z in/on Vessel V (2.2)

Two intermediate events must occur if an organism of Species S is to arrive in Area Z in/on Vessel V: Vessel V arrives in Area Z (2.5); AND Vessel V is infected with Species S from Area Y (2.6) (Fig. 2.2). The arrival of Vessel S in Area Z can be determined by the vessel’s cruising habits (2.7) so there is no need to develop this event further. For Vessel S to arrive in Area Z infected with Species S from Area Y the following two events must occur: Vessel V becomes infected with Species S from Area Y (2.8); AND Species S survives the voyage to Area Z (2.9).

Table 2.3 Expert Panel 2–Expert background. NZ Cgov.= New Zealand Central government agency, NZ R.agency= New Zealand research angecy, NZ Lgov.= New Zealand Local government agency, O. R.agency= Overseas research agency, P= Doctor of Philosophy, M= Master of Science, D= Doctor of Vetrinary Medicine, ϕ= Based on reports/publications or previous knowledge the author assumed the expert had experience in that field, but this information was not corroborated by the expert.

	Expert													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Country/Region														
Australia									X					X
New Zealand	X	X	X	X	X		X	X		X	X	X	X	
South America						X								
Current work place														
NZ Cgov.–A	X		X											
NZ R.agency–A		X												
NZ R.agency–B				X	X									
NZ R.agency–D												X		
NZ R.agency–E											X			
O. Cgov.–A									X					
O. R.agency–E						X								
O. R.agency–F														X
Independent contractor							X	X		X			X	
Field of experience (years)														
Marine Biology	11	10		4		10	10	4	15	ϕ	ϕ	ϕ		5
Marine Invasions	6	4	4			2			5	ϕ	ϕ	ϕ	ϕ	5
Freshwater Invasions											ϕ			
Terrestrial Invasions			4											
Risk Assessment		4				10			3		ϕ			5
Biosecurity management	6		4			1							ϕ	
Recreational vessels	11	21	2	9		5	10	ϕ	6	ϕ	ϕ	ϕ	ϕ	10
Highest education degree	M	P	D	M	P	P	P	P	P	P	M	M	-	M
Exercises completed	2	2	2	2	2	2	1	1	1	1	1	1	1	1

The voyage survival of Species S depends on the interaction of several factors, such as species characteristics (e.g., temperature and desiccation tolerance), environmental conditions of the vessel component and the location of the infected component (e.g., hydrodynamic forces, temperature and salinity), and characteristics of the trip (e.g., voyage duration). For example, it is considered that a large proportion of hull biofouling might (partially or completely) die as a result of water temperature or salinity changes experienced along the trip (Minchin and Gollasch 2003). Differential survival among hull biofouling assemblages has been related to the hydrodynamic forces (i.e., drag) experienced by organisms, which is highly dependent on vessel speed and the organisms' morphology (Coutts et al. 2007, Coutts et al. 2010). Similarly, cooler and damper conditions can increase the survival of hull fouling zebra mussels (Dreissena polymorpha) to aerial exposure from five days (Johnson and Padilla 1996) to two and a half weeks (Pollox et al. 2003). Therefore, in order to assess the voyage survival of Species S it is necessary to develop species-specific survival models for each of the potentially infected components of the vessel (2.12).

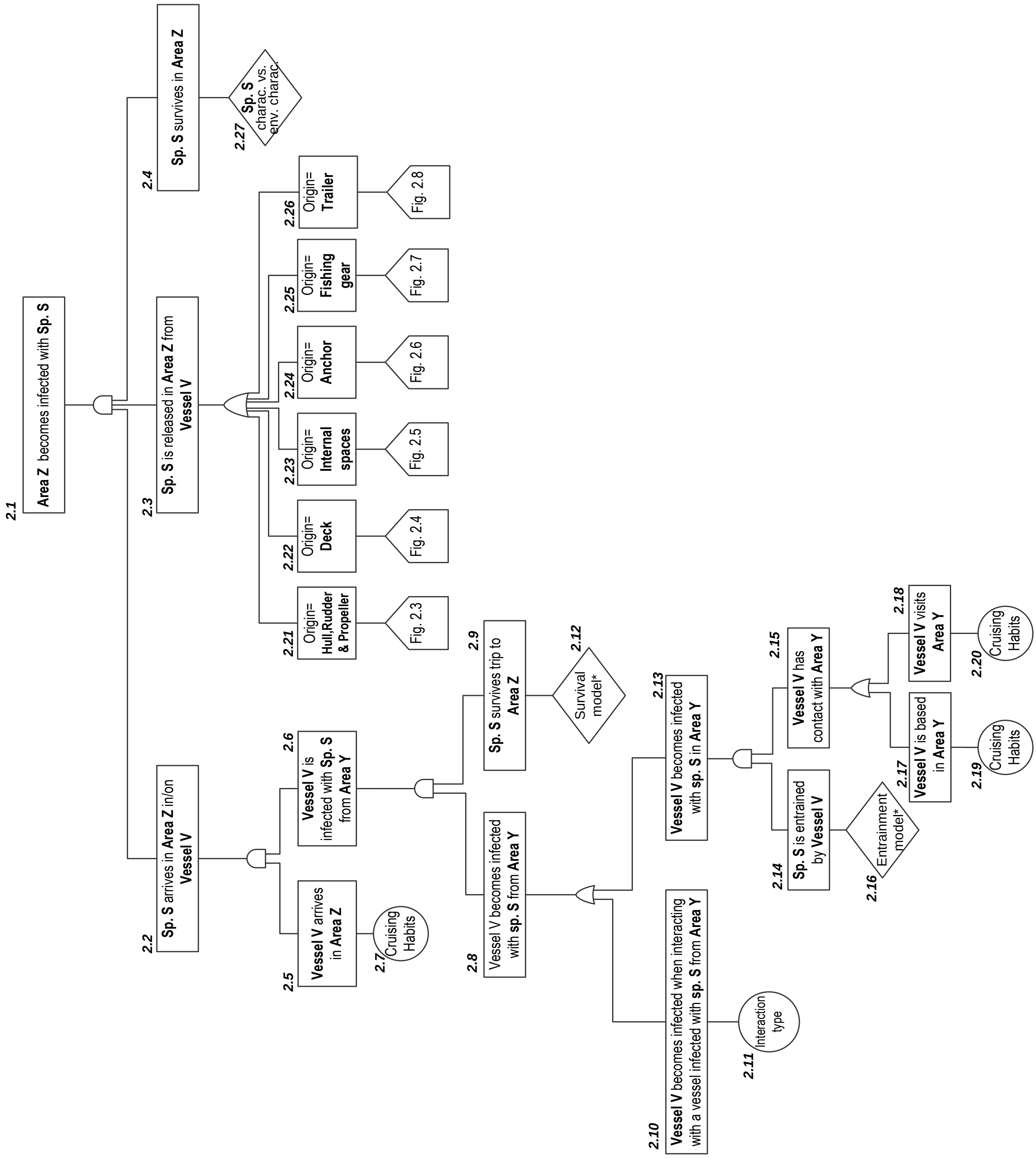

Figure 2.2 First part of the fault tree developed for the marine invasion process via recreational vessels. The top event is the infection of Area Z. The figure shows the sequence of events from the infection of the Vessel V in Area Y to the release and survival of Species S in Area Z. (*The survival model has to be specific for each vessel component).

Vessel V can become infected with Species S from Area Y (2.8) either: by interacting with a vessel infected with species S from Area Y (2.10); OR by having direct contact with Area Y (2.15) AND entraining species S (2.14). Whether or not Vessel V becomes infected from other vessels depends on their interaction type (2.11). For example, as gear (e.g., fishing, Scuba–diving) has the potential to translocate NIS (Carlton 2001, Neil et al. 2005, GISP 2008), exchange of infected gear between vessels could infect Vessel V with Species S. Similarly, if vessels infected with Species S from Area Y and Vessel V visit the same marine facilities (e.g., anchoring and mooring areas, marinas), the latter could become infected. In fact, marinas have been identified as NIS havens in part because of this potential interaction (e.g., Bax et al. 2003, Floerl et al. 2004).

Vessel V has contact with Area Y (2.15) because either: Vessel V is based (moored or launched) in Area Y (2.17); OR Vessel V visits Area Y (2.18). These two events are determined by the vessel's cruising habits (2.19, 2.20). However, whether Species S is entrained by Vessel V (2.14) in Area Y is determined by the interaction of characteristics of Species S (e.g., reproductive state, dispersal mechanisms, density) and Vessel V (e.g., residence time in Area Y, activities while in Area Y, maintenance habits). Therefore, entrainment models for each vessel component must be developed to analyse this risk (2.16). For example, studies have related the type, age and maintenance of the antifouling paint with the likelihood of hull biofouling of a vessel (Floerl and Inglis 2005, Piola et al. 2008).

As with anchors and other aquaculture structures, the likelihood of the anchor of a vessel becoming infected via fouling (not including entanglement of fouling and non-fouling taxa such as decapods and seaweeds) increases with the time that it is left in the water. Similarly, the density of NIS organisms and propagules affects the likelihood of entrainment (Hayes 2002b, Ruiz et al. 2000a). However, as indicated by Barry et al. (2008) in their analysis of the ballast water translocation, it is reasonable to assume that if a target species (in this case Species S) is not present or cannot be entrained then it does not represent a threat.

2.3.2.2 Species S is released in Area Z from Vessel V (2.3) and survives in Area Z (2.4)

As any of the five components of Vessel V could be infected, each component (i.e., 2.21– 2.26) was analysed as a potential source of Species S. Release of Species S in Area Z from Vessel V (2.3) may occur from any of the following components: Hull, Propeller and Rudder (Hull) (2.21); OR Deck (2.22); OR Internal spaces (2.23); OR Anchor (2.24); OR Fishing gear (2.25) (Fig. 2.26). Fault trees for each of these components, and rationale for their inclusion, are detailed in subsequent sections.

The likelihood that Species S survives in Area Z (2.4) has to be determined through the development of a specific model. The model must be based on the biology of the species, and the environmental characteristics of Area Z (2.23). Survival of arriving organisms (or propagules) of Species S may be reduced if Area Z mismatches (physically or chemically) the requirements of this species (Smith et al. 1999, Havel et al. 2002). Furthermore, the assumption that Species S survives, whether or not Area Z becomes infected (i.e., Species S is established) depends on a number of factors affecting invasion success, such as propagule pressure and invasion resistance (e.g., Stachowicz et al. 2002, Allen and Williams 2003, Chen and Hovel 2010, Dumont et al. 2011, Tomas et al. 2011,), and may involve a considerable element of chance (Ruiz et al. 2000a, Drake and Lodge 2006). The accuracy, and thus validity, of such models are highly dependent on the baseline data and knowledge available for both the species and environment considered.

Survival and establishment of Species S in Area Z can be predicted based on species distribution and ecological niche models (reviewed in Guisan and Zimmermann 2000; e.g., Leathwick et al. 2008, Maxwell et al. 2009, Carrasco and Baron 2010, Tyberghein et al. 2012). These models assume that the fitted relationship between the considered limiting environmental variables and the distribution of the species is an adequate representation of the realised niche[7] of such species under a stable equilibrium constraint (Franklin 1995, Guisan and Theurillant 2000). It is important for such predictions to consider the uncertainty introduced by the difference between the realised and fundamental niche, which has been experimentally demonstrated by studies such as Ellenberg (1953), Mueller-Dombois and Ellenberg (1974), Austin (1982) and Davis et al. (1998). However, as noted earlier, the model in this chapter is focused on the release of NIS into a new area, hence for present purposes, the potential for survival and establishment is not developed further.

2.3.2.3 Fault trees for release of Species S in Area Z (2.3)

Fault trees depicting the release of Species S in Area Z are shown in Figures 2.3–2.8 for each of the components 2.21 to 2.26.

Hull (Fig. 2.3)

Hull fouling is a well-recognised mechanism for the transfer of NIS via recreational vessels (e.g., Thresher 1998, Lambert and Lambert 2003, Minchin and Sides 2006, Dijkstra et al. 2007, Clarke Murray et al. 2011, Hewitt et al. 2011). As the Hull is usually underwater, the only infection mode considered for the Hull component, which includes the external hull, rudder and propeller is 'fouling' (Fig. 2.3).

Information on the life-cycle of Species S (3.6) and environmental data of Area Z (3.7) (e.g., temperature, salinity) can be used to estimate the likelihood of natural release of propagules. For example, rise in sea temperature was considered the trigger for the spawning of the NIS Mediterranean mussel *Mytilus galloprovincialis* found attached to a vessel that had been towed from the Washington–Oregon area to Hawaii (Apte et al., 2000).

If Species S is present in Vessel V as fouling (3.1), two events can lead to its release into the environment: the release of propagules (3.2); OR the release of organisms (3.3). The release of propagules can occur naturally (3.4); OR be induced by disturbances (3.5) (Apte et al. 2000, McCarthy et al. 2003, Hopkins and Forrest 2008).

Release of propagules also can be induced by disturbances (3.5). Determining this event requires information on the type of disturbances that can occur in Area Z and the type of disturbances that can lead Species S to release propagules (e.g., (McCarthy et al. 2003)). This is demonstrated by other non-hull fouling species such as the invasive alga *Caulerpa taxifolia,*

[7] Introduced by Hutchinson (1957), the concept of realised and fundamental niche establishes that while the fundamental niche of a species describes all possible combinations of resources and conditions under which species' populations can grow, survive, and reproduce, the realised niche describes the more limited set of resources and conditions necessary just for the persistence of species' populations in the presence of competitors and predators (Booth and Murray 2008).

where intrinsic biological factors (Renoncourt and Meinesz 2002) and temperature (Meinesz et al. 1995) can influence the rate of thallus fragmentation (i.e., generation of viable propagules).

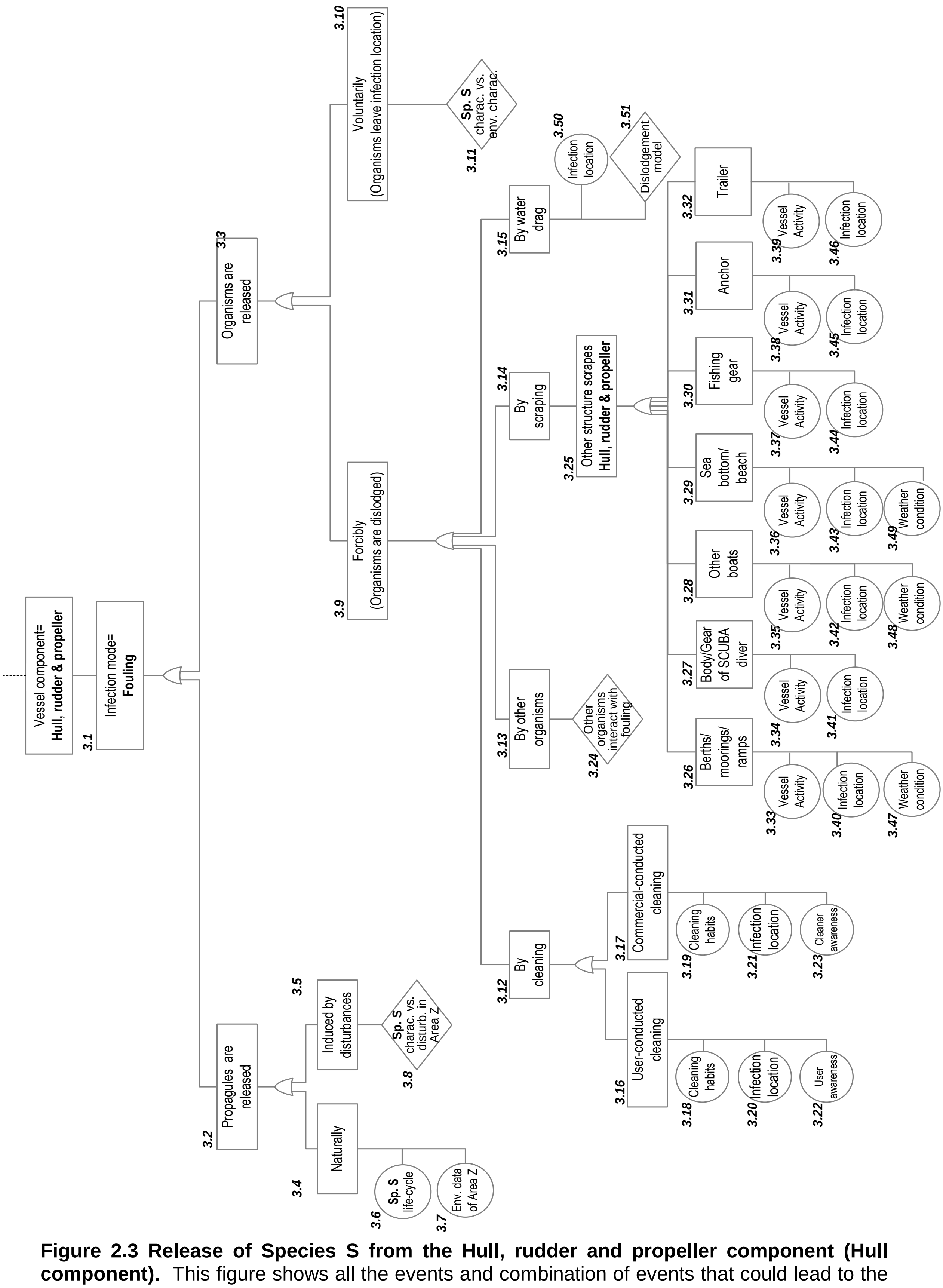

Figure 2.3 Release of Species S from the Hull, rudder and propeller component (Hull component). This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. (charac.= characteristics, disturb.= disturbances, env.= environmental).

Waves generated by storms (West et al. 2007), as well as grazing by herbivores (Zuljevic et al. 2001, Gollan and Wright 2006) also can influence the rate of propagule production from such fragmentation. Hence, knowledge of the biological and behavioural characteristics of Species S, as well as information on environmental conditions, is required (3.8).

Organisms can be released into the water forcibly (3.9) OR voluntarily (3.10). Whether organisms leave the Hull voluntarily is determined by mobility and behaviour of Species S under certain environmental conditions (3.11). Organisms associated with the biofouling that are known to be capable of independent detachment include crabs, fishes, sea stars, shrimp, snails and plankton (Foster and Willan 1979, Carlton and Hodder 1995, Coutts et al. 2003). Conversely, dislodgement of other organisms, such as barnacles, sea squirts and sponges is more likely to be the result of an external agent or process (e.g., contact with artificial structures, cleaning).

Organisms can be forcibly (deliberately or accidentally) dislodged into the environment by cleaning (3.12), OR other organisms (3.13) (e.g., predation), OR scraping (3.14), OR water drag (3.15). Dislodgement by cleaning can be the result of user-conducted cleaning (3.16) OR commercially-conducted cleaning (3.17) (Hopkins and Forrest 2008). Whether these events dislodge organisms is determined by cleaning habits (3.18, 3.19), infection location (3.20, 3.21) and user (3.22) or cleaner (3.23) awareness. In fact, there is an increasing interest in the assessment of current (and development of new) cleaning tools (e.g., multi-brush and water-blasting) with the ability to contain the materials removed from the Hull during the cleaning process (Floerl et al. 2005b, Hopkins et al. 2008, Bohlander 2009). Dislodgement by other organisms is determined by the presence of organisms that interact with the fouling community (3.24) (e.g., predation on biofouling). These organisms can be part of the fouling community itself or be present in Area Z. Organisms can be dislodged by scraping (3.14) when the Hull has contact with other structures in Area Z (3.25).

The structures that the Hull can have contact with are: boat ramps/berthing/mooring structures (3.26), SCUBA-divers and their gear (3.27), other boats (3.28), the sea bottom (3.29), Fishing gear (3.30), the Anchor (3.31), and the Trailer (3.32). Whether there is contact with these structures, and this contact scrapes organisms into the environment, is determined by the activity of the vessel (3.33–3.39) and the infection location (3.40–3.46). Weather conditions also determine whether there is contact with boat ramps/berthing/mooring structures (3.47), with other boats (3.48) or with the sea bottom/beach (3.49). In order to determine whether water drag dislodges organisms (3.15), it is necessary to identify the infection location (3.50), the hydrodynamic forces that work on it and the force required to dislodge the species. All of this information can be used to develop a dislodgement model (3.51). For example, the invasive club tunicate *Styela clava* has higher attachment strength and lower drag coefficient than its congener *Styela gibbsii* (Clarke Murray et al. 2011), which implies that the latter could be dislodged more easily by hydrodynamic forces.

Deck (Fig. 2.4)

Two infection modes are considered for Deck: water/sediment retention (4.1) and fouling (4.2). Water and sediment could be retained on a vessel's deck for a variety of reasons. For example, it could be sourced from seawater spray and splash as well as from muddy gear (Hayes 2002a, Fofonoff et al. 2002). Similarly, the Deck could be fouled with material sourced from fishing and dredging that could be subsequently released to the environment by anthropogenic (e.g., washing) or natural (e.g., waves) forces.

If the component Deck is infected with water or sediment (i.e., organisms or propagules of Species S may be present), this retained water/sediment can be released into the environment (4.3) by: Natural forces (4.4); OR Anthropogenic forces (4.5); OR Accident (4.6). Three events, described here as Wind (4.7); OR Rain (4.8); OR Waves (4.9) can lead to the release of Species S into the water by natural forces via water or sediment retained. Whether these events occur is determined by the infection location (4.10–4.12) and weather conditions (4.13–4.15).

Anthropogenic forces refer to the discharge of retained water/sediment by the user/cleaner (4.16). The infection location (4.17), cleaning habits (4.18) and user/cleaner awareness (4.19) determine whether this event leads to the release of Species S into the environment. Accidents (4.6) encompass all of the events that lead Vessel V to capsize or sink (4.20). Factors, such as weather, activity, user experience, among several others, will influence these events. For example, in the United States alcohol/drugs is a contributing factor to the annual rate of 5.3 fatalities per 100000 numbered boats resulting from vessel accidents (Lawrence et al. 2006).

If Species S is present on the Deck as fouling, the same two events as described for Hull (Fig. 2.3) can release it into the environment: organisms are released (4.21); OR propagules are released (4.22). Similarly, organisms can be released into the water forcibly (4.23) OR voluntarily (4.24). Forcible release in this case could include accidents (4.27) in addition to natural (4.25) or anthropogenic forces (4.26). In the same way as for the water/sediment retained infection mode, the release of fouling organisms into the environment by natural forces can be the result of wind, rain or waves (4.28–4.30). However, release of organisms by birds also could be a possibility for the Deck component (4.28). For example, seabirds feeding on fishery products and their discards (which could occur when target and by-catch organisms lay on Deck) is a common event worldwide (Boswall 1960, Wassenberg and Hill 1990, Berghahn and Rosner 1992).

As with the Hull component, infection location (4.32–4.35) and weather conditions (4.36–4.38) determine whether these events occur. The release of organisms by anthropogenic forces (4.26) and accidents (4.27) can be modelled with the same series of events used for these components in the water/sediment retained infection mode (4.39–4.43). Organisms also can be released into the environment when they voluntarily leave the location of the infection (4.44), as described for the Hull component.

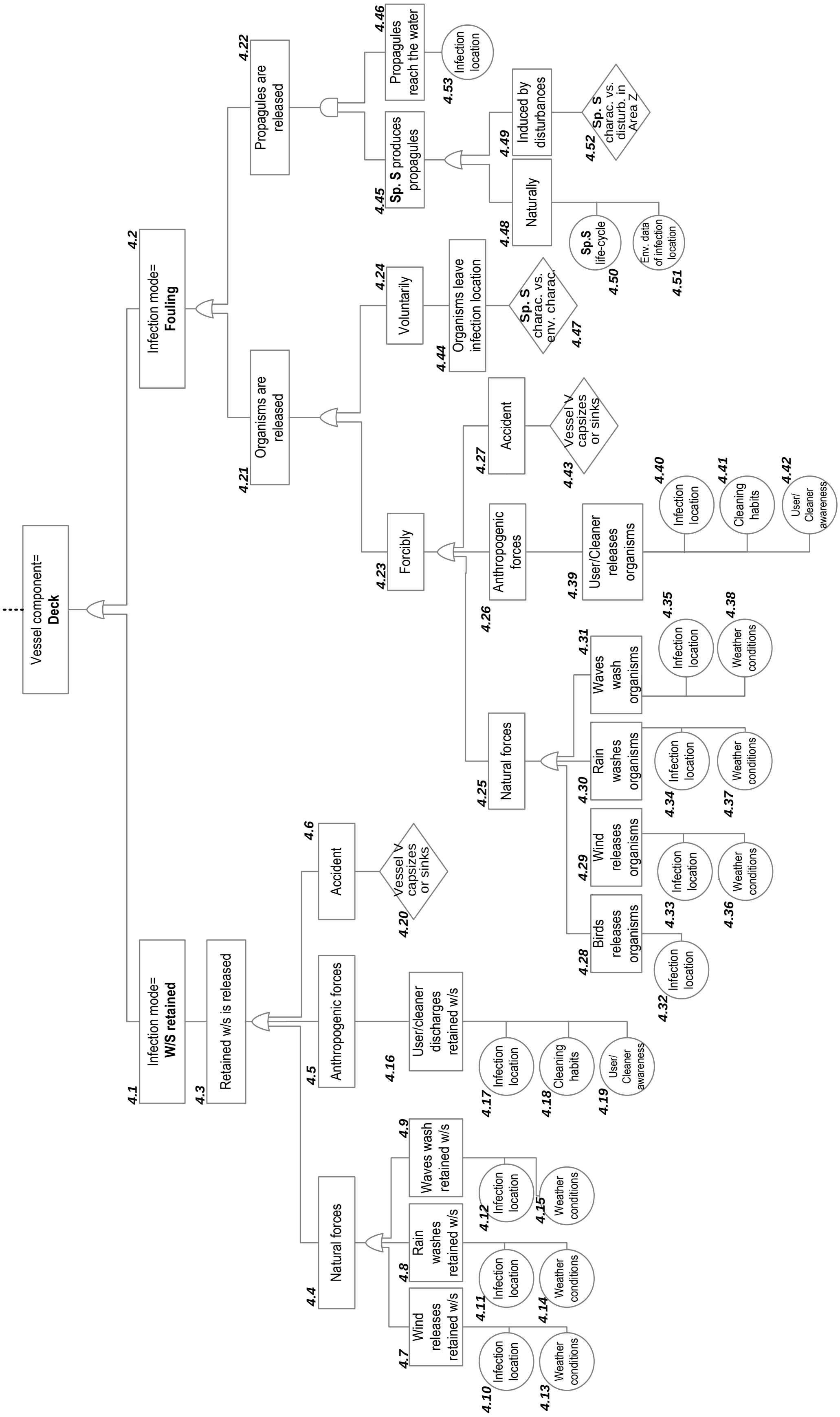

Figure 2.4 Release of Species S from the Deck component**.** This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. W/S= Water/Sediment. (charac.= characteristics, disturb.= disturbances, env.= environmental).

For the fouling infection mode, the event 'Propagules are released' (4.22) occurs only if Species S produces propagules (4.45) AND these propagules reach the water (4.46). The propagule production of Species S can be modelled based on the same events and factors (4.48–4.52) identified for the release of propagules in the Hull. However, in the Deck component whether propagules reach the water is determined by the location of the infection (4.53).

Internal spaces (Fig. 2.5)

The component 'Internal spaces' refers to spaces, such as sea/gray-water inlet-outlets, bilge (open and closed), storage rooms and boxes, anchor well, holding tanks (including ballast tanks present in some recreational vessels), pumps, toilet/shower and wheelhouse, among others (Hayes 2002a). Two infection modes are considered for Internal spaces: water/sediment retention (5.1) and fouling (5.2). For example, water contained in 'the keel centre' (i.e., bilge) of some vessels arriving in New Zealand from the South Pacific has been found to contain small fish (Dodgshun et al. 2007). Similarly, the risk of transporting NIS associated with the ballast water of commercial vessels (e.g., Gollasch et al. 1998, Bailey et al. 2003, Radziejewska et al. 2006, Barry et al. 2008, Simkanin et al. 2009) would be present in the ballast water of recreational vessels; although at a smaller scale. In the case of fouling, Internal spaces, such as sea chests could pose a risk of entrainment and transport of NIS that is qualitatively similar to that described by Richards (1990), Carlton (1999) and Coutts and Dodgshun (2007) for commercial vessels.

If Species S is present in the water/sediment retained, three events could release it into the environment (5.3): accident (5.4); OR discharge from Internal spaces (5.5); OR cleaning of Internal spaces (5.6). As for Deck, accident (5.4) encompasses all of the events that lead Vessel V to capsize or sink (5.7). Discharge of water/sediment from Internal spaces can occur automatically (5.8) or manually (5.9). The factors that determine whether Species S is released by an automatic discharge process are infection location (5.10), weather conditions (5.11) and vessel activity (5.12). Similarly, the factors that determine the release of Species S by a user-controlled discharge are infection location (5.13), weather conditions (5.14), vessel activity (5.15) and user awareness (5.16). Whether the cleaning of Internal spaces results in the release of Species S into the water is determined by the infection location (5.17), cleaning habits (5.18) and user awareness (5.18).

If Species S is present in the Internal spaces as fouling (5.2), it could be released into the environment in the same way as described for Hull and Deck, (i.e., as organisms, fragments, or propagules). Organisms are released because either the discharge process dislodges them into the water (5.22) OR the user releases them during cleaning activities (5.23). The first event occurs only if there is discharge of the internal space (5.24) AND if this discharge dislodges Species S (5.25).

As with the retained water/sediment, discharge of Internal spaces can result from: an accident (5.26); OR automatic discharge (5.28); OR user-controlled discharge (5.25), with similar lower events also applying (5.27, 5.30–5.36). Note that, in order to determine whether the discharge process dislodges Species S (5.23), it is necessary to have an understanding of

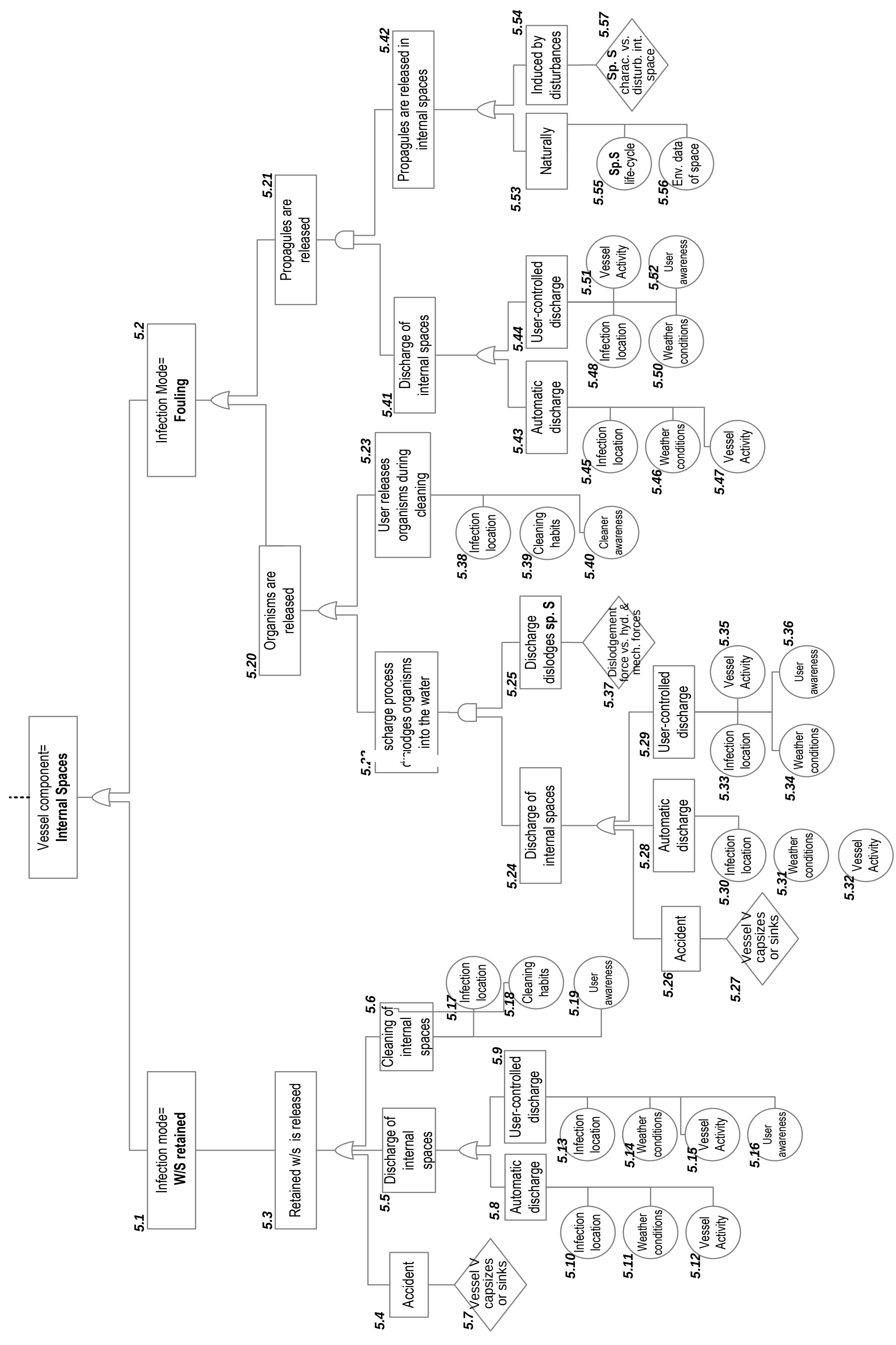

Figure 2.5 Release of Species from the Internal spaces component (Water/Sediment retained-Fouling). This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. (charac.= characteristics, disturb.= disturbances, hyd.= hydrodynamic, int.= internal, mec.= mechanical).

the force required to dislodge the species, and the mechanical and hydrodynamic forces that work on the infected space (5.33) (e.g., Clarke Murray et al. 2011, Coutts et al. 2010). The second event, 'user releases organisms during cleaning', is determined by infection location (5.38), cleaning habits (5.39) and cleaner awareness (5.40).

Propagules are released into the water only if Species S releases propagules in the internal space (5.42) AND there is discharge from that space into the environment (5.41). Whether there is a discharge of the internal space is determined by the same factors mentioned above (5.43–5.50). The event 'Propagules are released in internal spaces' (5.42) can be modelled by the same events and factors (5.53–5.57) considered for the release of propagules in the Hull component. However, in this occasion the environment considered is the internal space and not Area Z. This is why both releasing propagules AND discharge of internal space needs needs to happen.

Anchor (Fig. 2.6)

Two infection modes are considered for the Anchor: water/sediment retention (6.1) and fouling (6.2). Water and sediment (and associated organisms) often are retained on anchors, for example after deployment in soft-sediment habitats. Retained water/sediment can be released directly into the environment (6.4) OR onto the Deck (6.3) and from here into the environment. Water/sediment from the Anchor released via the Deck (6.3) is represented by the fault tree developed for that component (6.5, Fig. 2.4). Retained water/sediment can be released into the environment when there is an accident (6.6); OR the Anchor is deployed (6.7); OR the Anchor is cleaned (6.8).

The Anchor also may be infected by fouling, as has been suggested for fragments and propagules of the invasive alga *Caulerpa racemosa* (Klein and Verlaque 2008) and clearly demonstrated by West et al. (2007) for *C. taxifolia*. In such instances, the occurrence of at least one of two events can potentially release Species S into the environment: organisms are released (6.11); OR propagules are released (6.12). As with water/sediment retained, fouling can be released onto the Deck (6.13); OR directly into the environment (6.14). Organisms can be released into the environment following an accident (6.16); OR when the Anchor is deployed (6.17); OR when the Anchor is cleaned (6.18).

In the case of Anchor deployment, risk arises when organisms are dislodged (6.21), which can occur by scraping (6.23); OR by water drag (6.24). Scraping of the Anchor can occur as a result of contact with the seabed (6.25). Whether the seabed dislodges Species S by scraping depends on the infection location (6.26) and bottom type (6.27). In order to determine whether water drag dislodges Species S, it is necessary to know the force required to dislodge organisms (e.g., McKenzie and Bellgrove 2009, Clarke Murray et al. 2011) and the hydrodynamic forces encountered when the Anchor is deployed (6.28). For example, entangled fragments of *C. taxifolia* are often dislodged when an anchor is re-deployed (West et al. 2007). Whether organisms are released when the Anchor is cleaned depends on cleaning habits (6.29) and user awareness (6.30).

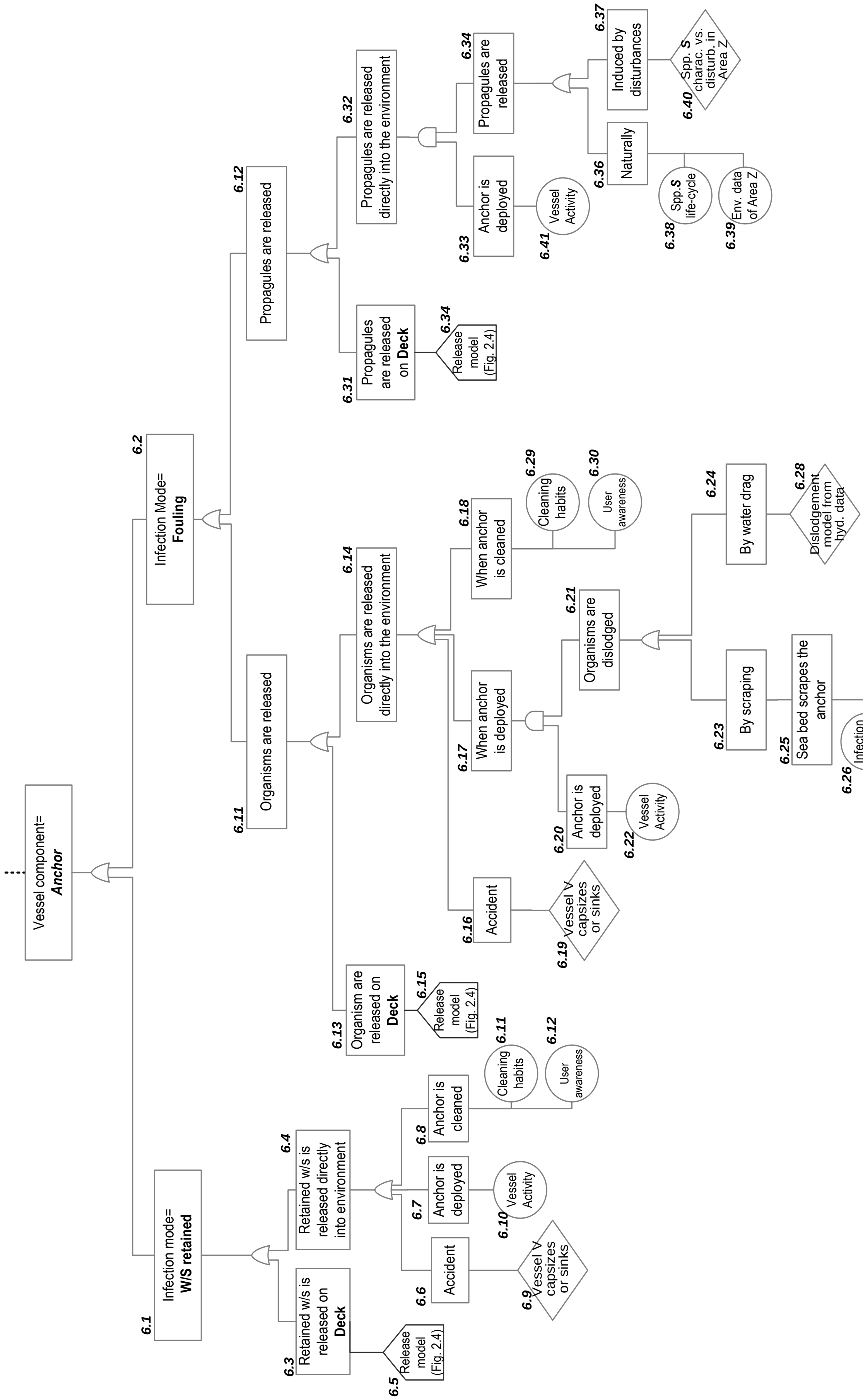

Figure 2.6 Release of Species S from the Anchor component. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. (charac.= characteristics, disturb.= disturbances, hyd.= hydrodynamic).

As with organisms, propagules can be released onto the Deck (6.31); OR directly into the environment (6.32). For propagules to reach the environment directly the Anchor has to be deployed (6.33) AND propagules have to be released (6.34). For example, in the case of the Asian kelp *Undaria pinnatifida*, mature plants on a fouled anchor that are out of the water for several hours (and become partially dehydrated) are likely to release spores upon redeployment because of rehydration of the reproductive sporophyll (Forrest and Blakemore 2006). Such behaviour following hydric stress is common to a wide range of algae (e.g., the invasive red alga *Grateloupia lanceolata* (Ye et al. 2012), the thalloid alga *Gelidium canariensis* (Garcia-Jimenez et al. 1999), and the intertidal turf alga *Endocladia muricata* (Hunt and Denny 2008)). The deployment of the Anchor is defined by the activity of the vessel (6.35). The release of the propagules from the Anchor can be modelled by the same events and factors identified for this event in components Hull and Internal spaces (6.36–6.40). Similarly, whether propagules released onto the Deck (6.31) reach the environment can be modelled by the fault tree for the Deck component (6.34, Fig. 2.4).

Fishing/diving gear (Fig. 2.7)

Shipboard transport in fouled fishing nets, ropes and similar gear has been proposed as a potential human-mediated pathway of spread for *C. taxifolia* (Meinesz et al. 1993, Sant et al. 1996, Relini et al. 2000), *C. racemosa* (Ruitton et al. 2005) and *Codium fragile tomentosoides* (Carlton and Scanlon 1985, Schaffelke and Deane 2005). While there appears to be no conclusive evidence relating to retained water or sediment in a marine context, risks from these are entirely conceivable (e.g., from sediment and associated biota retained in lines, nets and recreational dredges). This is supported by freshwater examples, such as the diatom *Didymosphenia geminate* (Kilroy and Dale 2006, Kilroy and Unwin 2011) and the mud snail Potamopyrgus antipodarum (Davis and Moeltner 2010), which are believed to be carried by vector such as fishing gear.

The infection modes, events and factors considered for the Fishing gear (7.1–7.48) are the same as considered for the Anchor component in Figure 2.6, with infection modes being water/sediment retained and fouling. The main difference with the Anchor component is that the release of fouling organisms or fragments from Fishing gear directly into the environment (7.13) is divided into forcibly (7.18) and voluntarily (7.12). Forcible release (7.18) is modelled by the same events and factors identified for the release of organisms in the case of Anchor (7.20–7.35). Whether organisms leave the Fishing gear component voluntarily (7.19) on the other hand, is determined by the infection location (7.36), the species characteristics, mobility and behaviour, and the environmental conditions (7.37). For example, during distribution surveys for the cryptogenic parchment tube worm *Chaetopterus* sp. (Acosta 2002, Tricklebank et al. 2001), benthic organisms fouling the chain, rope and outside of the sampling dredge were more easily dislodged and released into the environment than organisms inside the dredge (H. Acosta, pers. obs.). Similarly, crabs entangled near the mouth of the dredge were more likely to free themselves than other less mobile organisms (e.g., bivalves) (H. Acosta, pers. obs.).

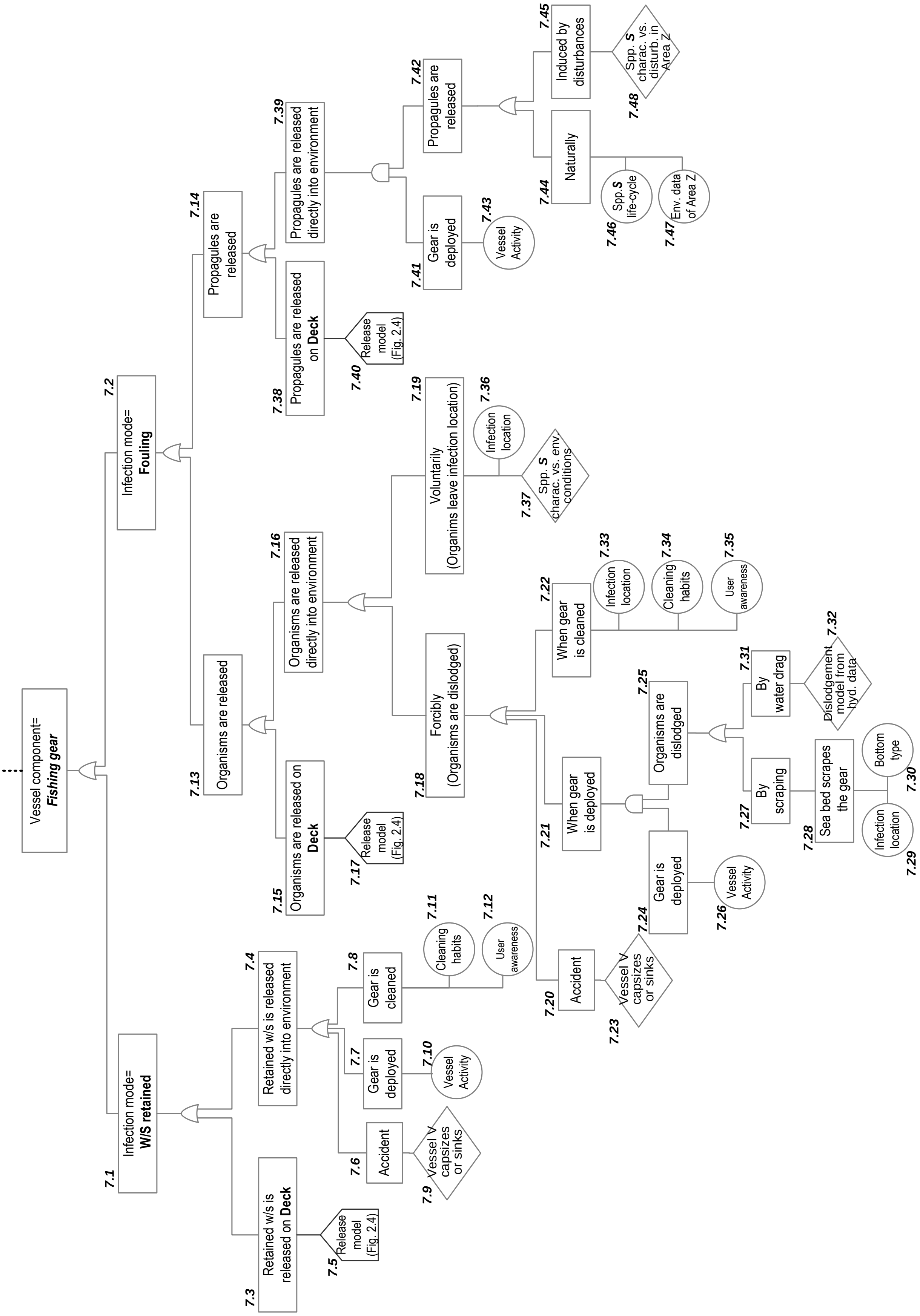

Figure 2.7 Release of Species S from the Fishing gear component. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. (charac.= characteristics, disturb.= disturbances, env.= environment, hyd.= hydrodynamic).

Trailer (Fig. 2.8)

Boat trailers have been identified as an important vector for NIS dispersal (e.g., Buchan and Padilla 1999, Bossenbroek et al. 2001, Johnson et al. 2001). Retrieving boats usually requires the immersion of part of the Trailer in the water, which increases the probability of releasing (entraining) both water/sediment or fouling into (from) the environment.

The infection modes considered for the Trailer are water/sediment retention (8.1) and fouling (8.2). Retained water/sediment can be released into the environment (8.3) when the Trailer is used to launch or retrieve the vessel (8.4); OR when the Trailer is cleaned at the beach or boat ramp (8.5). Whether retained water/sediment reaches the water when retrieving/launching the vessel depends on the infection location (8.6) and user awareness (8.7). Similarly, cleaning habits (8.8) and user awareness (8.9) will determine whether retained water/sediment reach the marine environment during cleaning of the Trailer (8.5). Fouling, as organisms or propagules, can be released into the environment when the Trailer is used to launch/retrieve the boat (8.12, 8.35) or is cleaned at the beach or a boat ramp (8.13). Intermediate and basic events similar to those described for the Hull component (Fig. 2.3) can be used to represent these events (8.17–8.42). In this case, dislodgement by scraping can be the result of contact with the Hull, boat ramp, beach, or cleaning activities. User awareness (8.24–8.27) and infection location (8.28–8.31) are the basic events for these.

2.3.3 Release model application

In order to demonstrate the applicability of the model, specific invasion scenarios are considered using the realised, or potential release and establishment of three recognised pest organisms to Port Nelson in Tasman Bay, New Zealand. The first two species (the Asian kelp *U. pinnatifida* and the colonial tunicate *Didemnum vexillum*) are already established, and will almost undoubtedly have been spread by recreational vessel pathways to some extent (in addition to other vectors such as aquaculture and commercial shipping). The third species, *S. clava,* was initially detected and removed from a vessel hull in Port Nelson (Morrisey et al. 2006), but is not known to have established among the resident biota.

These examples are used to demonstrate that various release scenarios can be associated with recreational vessels depending on species, time of year, user activity and many other factors. Note that in all these examples, cleaning activities and user-induced water/sediment discharge are excluded as a mode of release, as these activities are precluded by local rules (Nelson City Council 2003). As vessels use berthing facilities when visiting Port Nelson, they are unlikely to deploy their anchors or fishing gear. Thus, these infection components are not considered as viable infection mechanisms for this particular analysis. Similarly, for simplicity, the example only considered moored vessels so the component Trailer was not analysed.

Didemnum vexillum

Although this species has not been listed on the New Zealand register of Unwanted Organisms, it has been identified as a potential fouling pest, and presents a significant t hreat to the

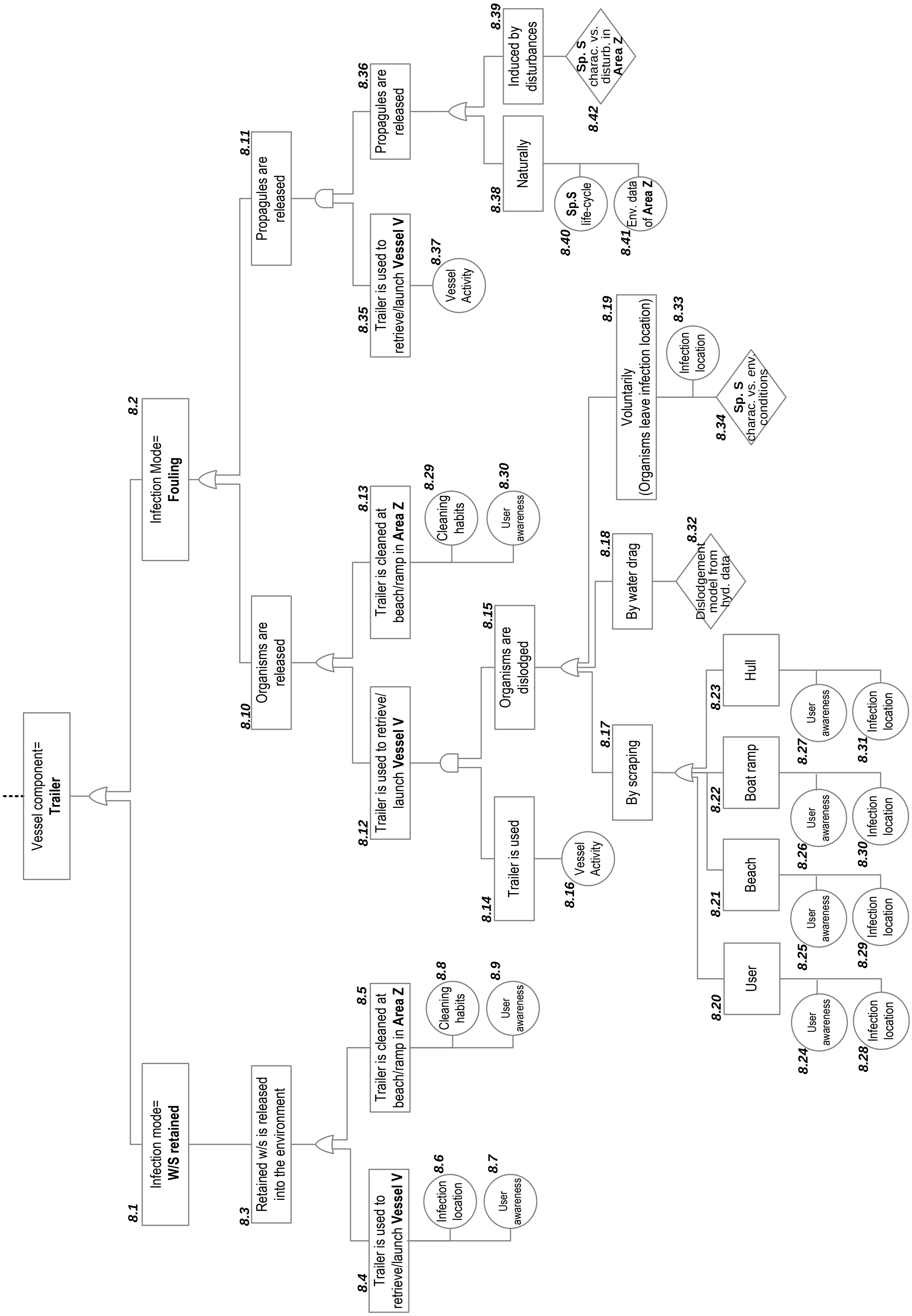

Figure 2.8 Release of Species S from the Trailer component. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. (charac.= characteristics, disturb.= disturbances, env. = environment, hyd.= hydrodynamic).

sector (Coutts and Sinner 2004). As a result, since its first report from Whangamata Harbour in 2001, surveillance programmes in New Zealand have often targeted *D. vexillum* (e.g., Inglis et al. 2006a,b,c, Morrisey et al. 2007), and a local control programme has been conducted in the Marlborough Sounds, a neighbouring area to Tasman Bay (Coutts and Forrest 2007).

This tunicate was first reported from the Tasman Bay region in 2002 (Coutts 2002) and is now relatively widespread throughout Port Nelson. To date, this species has been recorded almost exclusively on artificial structures across its distribution (Coutts and Forrest 2007). The exact time and means of infection of Port Nelson are both unknown, but the latter was almost certainly vessel-mediated. The natural dispersal potential of *Didemnum* appears limited (Forrest et al. 2009) and recreational vessel hull fouling is certainly recognised as an important mechanism for spread (Coutts and Forrest 2007, Auker and Oviatt 2008, Williams et al. 2010), to the extent that during a management programme started in 2006 considerable efforts were undertaken to ensure recreational vessels and their moorings were treated to eliminate *Didemnum* colonies (Pannell and Coutts 2007).

A fault tree that describes the potential role of recreational vessels in mediating the spread of *Didemnum* to Port Nelson (Fig. 2.9) highlights that the species can establish via the release of larvae or reattachment of fragments (Morris and Carman 2012). Hence, both mechanisms may be important in spread via hull fouling. Fragmentation could be important year-round as a release mechanism, in addition to forcible dislodgment of fragments (e.g., by accidental scraping of the Hull against mooring structures). Fragments are likely to be naturally released in mid-to-late summer when the species produces drooping tendrils (Valentine et al. 2007). In comparison, release via larvae will have a restricted window, since larval maturation and recruitment in Port Nelson does not occur during cooler winter months (L. Fletcher, Cawthron Institute, unpubl. data).

In addition to fragment release from hull fouling, fragments can also be produced in other ways, for example when lifting structures infected with *Didemnum*, such as moorings and aquaculture lines (H. Acosta, pers. obs.). In such instances *Didemnum* often can be observed on the vessel deck and could conceivably be released to the environment upon return to port during cleaning, or bilge water discharge. However, as mentioned above, the cleaning in Port is prohibited so the only viable mechanism for the discharge of fragments of this species into the environment would be forcibly through natural causes.

Undaria pinnatifida

This annual kelp was first recorded in Port Nelson in 1997 and was probably introduced via a barge. Like *Didemnum*, *Undaria* has a limited natural dispersal ability (Forrest et al. 2000, Schaffelke et al. 2005), with recreational vessel fouling as a widely recognised pathway for the spread of this species at regional scales (Hay 1990, Schaffelke et al. 2006). The release of spores from fouling of vessel hulls by mature *Undaria* sporophytes is generally regarded as the highest risk and most common invasion mode for *Undaria* (Hay 1990). Hence, this invasion mode will be related to the maturity of the plant over the period a vessel is in Port. Similarly, as demonstrated by Sliwa et al. (2006), mature sporophytes dislodged from the substrate (in this particular case the hull of the vessel) can remain viable and release spores while drifting, which generates greater dispersal than transport by spores alone.

During late summer and autumn mature sporophytes often are absent in the Tasman Bay region (McClary and Stuart 2004), and the likelihood of establishment following dislodgement of the kelp's microscopic gametophyte life-stage is probably relatively low. As noted above, *Undaria* also is recognised as having the potential to be entangled in anchors or fishing gear, such as nets. These mechanisms have been hypothesised as the means by which *Undaria* has been spread to relatively remote coastal areas in Tasmania, Australia (Sanderson 1990). Accordingly, the fault tree for *Undaria* release also would need to consider these components, and acknowledge the various associated release mechanisms that could occur in port (e.g., washing of mature plants or reproductive fragments from the deck, release of spores in bilge water) even though these events may be of low risk compared with hull fouling.

It is important to considered that, as with *Didemnum,* the release of *Undaria* into the environment is limited to the discharge of propagules and fragments forcibly through natural causes, since cleaning activities and voluntary water discharge are prohibited in Port Nelson,. Thus, the fault tree for *Undaria* release is the same as already described for *Didemnum* release (Fig. 2.9). The reduced model showed in Figure 2.9 makes the identification of the invasion sequence/s easier and thus, along with the description and analysis of release models for the Hull (Fig. 2.3) and Deck (Fig. 2.3), could assist scientists to define research priorities and managers to identify effective intervetion points and cost-effective preventinve measures. Some scenarios (e.g., vessel capsizing), although obvious, have not been incorporated in management plans (e.g., Pest Management Plans from Regional Councils).

Styela clava

This solitary tunicate was first recorded in New Zealand in 2005 in Auckland (Davis and Davis 2006), and has subsequently been reported from both a northern location (i.e., Tutukaka Marina) and a southern location (i.e., Lyttelton Port, Christchurch) (Gust et al. 2008). *Styela* was discovered and removed from the hull of a vessel in Port Nelson in 2006 (Morrisey et al. 2006). Several specimens have since been removed from piles and pontoons in the port (Top of the South Marine Biosecurity Partnership 2010), but frequent absence of the species in annual marine pest surveillance and baseline surveys suggests Styela has not become established in this area.

Recreational vessel fouling is recognised as an important pathway for the spread of Styela (Lützen 1999, Davis and Davis 2004, Ashton et al. 2006a), and is probably a key risk pathway for introduction of this species to the Nelson region. The latter would almost invariably lead to further spread of *Styela* to important aquaculture areas in the wider region. However, opportunities for the invasion of Port Nelson by *Styela* are likely to be low compared to *Didemnum* and *Undaria*. Assuming that *Styela* cannot reattach if dislodged, the only invasion mechanism for this species is larval release (Fig. 2.10). As such, it should be assumed that hull fouling is the only vessel component of relevance for this species. An association with other recreational vessel components (Deck, Internal spaces, Anchor and Fishing gear) appears

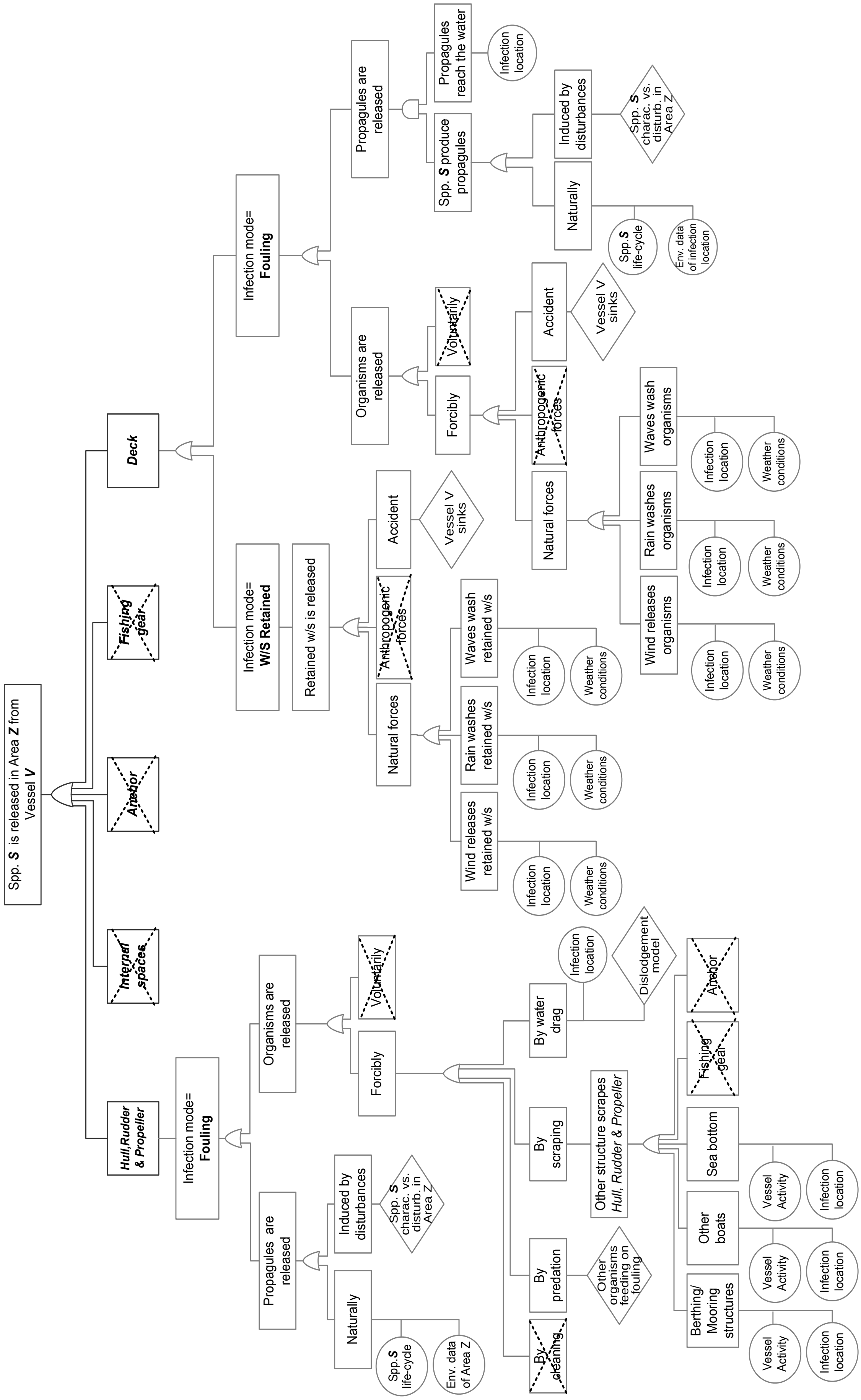

Figure 2.9 (see legend on next page)

Figure 2.9 Fault tree for the release of *Didemnum vexillum* or *Undaria pinnatifida* in Port Nelson, New Zealand. (see figure on previous page). This figure shows all the events and combination of events that could lead to the release of *Didemnum vexillum* or *Undaria pinnatifida* from an infected recreational vessel when visiting Port Nelson. Dashed lines represent those events that, although present in the original conceptual model should not be considered here as they are not valid for this invasion scenario (i.e., species type and location considered). (charac.= characteristics, disturb.= disturbances, env.= environment

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less likely and to my knowledge has not been reported. Given a specific reproductive window for *Styela* based on a minimum temperature for spawning and larval release of 16–20°C (Davis 1997, Bourque et al. 2007), in Port Nelson this would typically give an invasion window of four months per year (i.e., December–March).

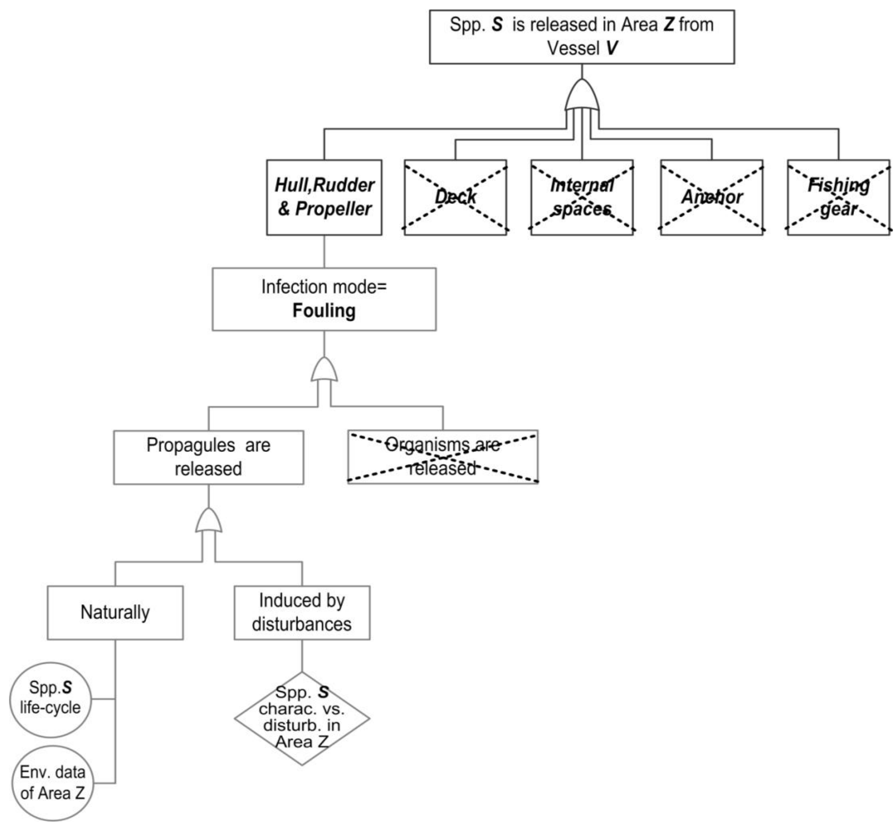

Figure 2.10 Fault tree for the release of *Styela clava* in Port Nelson, New Zealand. This figure shows all the events and combination of events that could lead to the release of *Styela clava* from an infected recreational vessel when visiting Port Nelson. Dashed lines represent those events that, although present in the original conceptual model, should not be considered here as they are not valid for this invasion scenario (i.e., species type and location considered). (charac.= characteristics, disturb.= disturbances, env.= environment).

2.4 DISCUSSION

Eradication of marine NIS has proven difficult, with limited successful eradication attempts reported in the literature (e.g., Bax 1999, Ferguson 2000, Culver and Kuris 2000, Willan et al. 2000, Miller et al. 2004, Wotton et al. 2004, Anderson 2005, Woodfield and Merkel 2006, Coutts and Forrest 2007). Due to the difficulty of eradication, the importance of preventing initial incursion is widely acknowledged (Ruiz and Carlton 2003, Hewitt et al. 2004, Finnoff et al. 2007). While the emphasis is typically on preventing the trans-oceanic transport of NIS to new countries, containing the further spread of NIS incursions can be critical to the post-border protection of a country's ecological, economic, social and other values (Hewitt et al. 2004, Forrest et al. 2006, Hulme et al. 2009, Biodiverse Limited 2010). This implies the need for control of human-mediated pathways of domestic spread (e.g., recreational vessels, aquaculture) on the basis that the natural spread of NIS can be restricted by barriers to their dispersal, or establishment. Knowledge of such barriers can be used to identify 'internal borders' around which it may be feasible to manage key vectors of spread (Forrest et al. 2009). Although management of domestic pathways may focus on NIS that are of concern as pest species, Forrest et al. (2009) suggest that for maintenance of values such as biodiversity, managing pathways to reduce the human-mediated spread of indigenous biota may be equally important.

2.4.1 Application of the fault tree model

The effectiveness of controlling NIS spread through human-mediated pathways is contingent on the identification and effective management of all vectors. Although recreational boating is recognised as an important pathway for the spread of NIS in marine environments (e.g., Minchin and Gollasch 2002, Neil et al. 2005, GISP 2008), most research to date has focused on hull fouling as the primary mechanism of spread (e.g., Floerl et al. 2004, Mineur et al. 2008, Davidson et al. 2010, Bell et al. 2011, Clarke Murray et al. 2011, Lacoursière-Roussel et al. 2012). The conceptual model presented here can be used for assessing ecological risks from recreational boating in a systematic and comprehensive manner. The model makes evident the variety of mechanisms in addition to hull fouling that potentially contribute to the spread of NIS via this pathway.

Evaluation of model application using the three case study species in Port Nelson, highlighted examples where the different non-hull fouling mechanisms of a vessel could be important invasion pathways. Both the conceptual model and case study species also highlighted the broad range of events, variables and interactions that can influence the release of NIS into the environment from any of the vessel components analysed. Such complexity should be acknowledged and addressed during the design and implementation of research and management programmes for recreational vessels in New Zealand, as to date, most of them have mainly targeted hull fouling (e.g., McClary 2001, Bohlander 2009, Sinner et al. 2009, Floerl et al. 2010a,b, Bell et al. 2011, Inglis et al. 2012a, Lacoursière-Roussel et al. 2012).

Events and mechanisms for which management is realistic and thus potentially effective, are identified by the model. For example, knowledge that larval release from hull fouling is the most likely invasion pathway for *S. clava* associated with recreational vessels, and that the invasion window has a seasonal dependency on larval maturation (Davis 1997, Bourque et al. 2007, McClary et al. 2008), could be used to guide key locations and times to undertake surveillance for this species. Conversely, identification of a greater complexity of potential release mechanisms for *Didemnum* and *Undaria* suggests a need for management approaches that do not focus exclusively on hull fouling.

The conceptual model highlights the importance of user awareness, vessel activity, characteristics of the species, infection location and environmental characteristics of the recipient area in the release phase of the invasion process. Most of the fault trees presented here have at least one of these identified as determining variables of basic events (see Figs. 2.3–2.8). Hence, the occurrence of subsequent events, and the release of the species in the recipient environment, would depend ultimately on these variables, and may need to consider time as factor where release has a strong temporal (e.g., seasonal) dependency. Characterisation of these variables would allow for the assessment of the risk of release under specific circumstances.

Increasing user awareness and, where feasible, management of vessel activity, could reduce the likelihood of NIS being released. For example, awareness has been identified as a key factor in the successful response to the presence of the NIS Asian green mussel *Perna viridis* on the hull of three navy vessels in Australia (Piola and McDonald 2012). Therefore, education programmes on marine NIS among boat owners aimed at increasing awareness such as 'Asian Seaweed (*Undaria pinnatifida*) found in Fiordland' (Environment Southland 2012), Vessel Cleaning (MAF 2011a), and Clean Marinas (www.cleanmarinas.org.nz) are likely to help preventing the transport and release of NIS via recreational vessels.

Although the modelling and assessment of some of the events identified in these fault trees would be difficult or unrealistic, it is important to acknowledge them in order to provide a comprehensive risk assessment tool. Therefore, all of the building blocks on which the model is based must be well considered. It is important to consider that, even where risks are largely unknown, difficult to quantify, or reflect highly stochastic events, this does not necessarily preclude management intervention. For example, it would be difficult and impractical to develop a dislodgement model for fouling from the Deck, Anchor and Fishing Gear components (Figs. 2.4, 2.6, 2.7). Furthermore, the dislodgement model would need to include spatial and temporal components that would make it highly specific, hence limit its applicability. However, by identifying activities, such as deck washing or the deployment of an anchor or type of fishing gear (e.g., scallop dredge, crayfish pot) as an event that could lead to the release of a NIS into the environment, managers could take a precautionary approach and define appropriate preventive measures. For example, these measures could include guidelines for treatment of contaminated gear, restrictions regarding anchoring or water discharge in high value localities such as marine protected areas, as has been suggested and promoted in parts of New Zealand for managing the spread of NIS such as *Undaria* and *Styela* (e.g., Guardians of Fiordlands' Fisheries & Marine Environment Inc. 2003, Gust et al. 2008, Piola and Forrest 2009, Dunmore et al. 2011).

The model, although it is general and comprehensive, cannot be universally applied in the form presented here. This was clearly highlighted by the Port Nelson case study, where depending on the species considered (*Undaria* and *Didemnum* vs. *Styela*) the component Deck needed to be included. Hence, the model would need to be modified according to the characteristics of recreational boating of each region or scenario considered. For example, one of the international experts in the first panel suggested that the fault trees representing the Anchor and Fishing gear components did not match the operational characteristics of boats.

However, experts with experience in recreational boating and fishing specifically in New Zealand, considered these trees a real representation of the components.

The model should be also modified when specific locations (e.g., anchorage areas, marinas) and vessel types (e.g., slow barges, keelers) are considered. For example, recreational yachts are more likely to deploy their anchor when visiting an anchorage area than when they are visiting a marina. On the other hand, recreational yachts mainly used for racing in Tasman Bay, are unlikely to use their anchor at all (G. Sticker, pers. com.). Therefore, the general release model should be modified to represent each of these scenarios. This includes the weight, or importance, given to each basic event and undeveloped event, which graphically in the model might be seen as equally important but, as explained above, different events would have more or less importance depending on specific circumstances. Similarly, the analysis of the process should focus on those components that could actually play an active role in the invasion process. In general, these modifications should reduce the complexity of the model (as seen when considering *Styela* in the case study), increase its accuracy and elucidate the steps of the invasion process where management may be feasible.

2.4.2 Utility of the fault tree analysis framework

Although usually associated with quantitative analysis, fault tree analysis is most often used as a hazard identification technique and to help design mitigation strategies (Wells 1996, Hayes 2002b, Crawley and Tyler 2003, Burgman 2005). In contrast to most hazard identification techniques, fault tree analysis forces the analyst to follow a systematic and reductionist approach not only to identify the components and potential hazards of the system, but also to determine the causal links among them (Crawley and Tyler 2003). Hence, it is unlikely that without following this approach, the thorough analysis of the invasion process depicted in the present model, where a wide range of variables and their interactions are identified and organised, would have been possible.

As with any hazard identification technique, fault tree analysis has some limitations. The first, and probably the most important limitation, is the reliance of fault tree analysis based on expert opinion. Lack of research and information on the marine invasion process often makes expert opinion necessary when designing and implementing risk assessment and management plans (e.g., Williamson et al. 2002, Forrest et al. 2006, Gust et al. 2008, Therriault and Herborg 2008, Sheehy and Vik 2010, Narščius et al. 2012), but ultimately the accuracy of risk assessment processes depends on the knowledge of the people that participate. The pathway model presented here has been developed by a diverse group of experts with different perspectives and areas of expertises on recreational boating risks. Steps were taken to minimise linguistic uncertainty with the method and to ensure that participants had a minimum common knowledge.

Secondly, the reductionist and forensic approach used by the fault tree analysis technique makes the development of quantitative models convoluted and time consuming. Even with the second set of exercises that started with a model previously reviewed, it took over six months for all participating experts to return all exercises, and not all of the experts that initially agreed to participate completed both exercises. Higher retention rates and shorter return times are likely to be achieved when using incentives (e.g., economic (Schneider and Johnson 1995)). Similarly, interactive group methods (e.g., group meetings, focus groups) may generate more ideas and reduce these setbacks (Meyer and Booker 1991, Clemen and Winkler 1999). However, in addition to making expert participation more difficult (or impossible in some cases, especially with overseas experts), inter–expert interaction can force or contrive consensus (Chhibber et al. 1992). By following a Delphi approach in the present study, the influence of one expert over another was diminished, and although consensus was achieved, individual opinions were preserved.

Despite being time consuming, this technique provides assurance that the pathway is analysed thoroughly, and the determining variables and events of the invasion process are identified. Also, once a comprehensive model is developed, it can be easily modified and revised, as demonstrated by examples in this paper. Another important limitation is that fault trees do not incorporate any time component. Hence, the analyst must ensure the conceptual model represents the release of NIS via recreational vessels at a given point in time and acknowledge the time-dependent factors that affect invasion risk.

Finally, uncertainty, usually divided into linguistic and epistemic (Regan et al. 2002, Burgman 2005), is an inevitable and thus important characteristic of modelling. In contrast to linguistic uncertainty, which arises from the vagueness and context dependency of the natural language, epistemic uncertainty reflects incomplete knowledge that results from variability and incertitude, measurement error, systematic error, natural variation, model uncertainty and subjective judgement (Regan et al. 2002, Burgman 2005). Although model uncertainty is harder to quantify than the others, it is usually more important and more likely to affect the results of the analysis (Morgan and Henrion 1990). Thus, reducing this uncertainty is a priority in modelling, which implies that users of this approach should base their analyses on a carefully developed conceptual model.

By overlooking and underestimating model uncertainty, researchers might generate incomplete and inaccurate models with systematic biases. Therefore, while the absence of quantitative application of the present model could be seen as a short-coming, the work was never intended to be a quantitative risk assessment or a fault tree analysis in its strictest sense. On the contrary, the model can be regarded as a sound conceptual framework that could underpin future quantitative analyses of the marine invasion process via recreational boating using fault tree analyses or alternative techniques. Importantly, the model here clearly highlights the fact that there are a range of invasive species transport mechanisms that need to be at least acknowledged as sources of uncertainty in any analysis. This, although apparently trivial, is an important contribution to this field, considering that the current literature for marine invasions via recreational boating focuses almost exclusively on hull fouling.

2.5 CONCLUSIONS

The conceptual model presented here reveals the consecutive steps that must occur for NIS to be introduced from recreational boats, and highlights the complexity of the invasion process even when only the ‘release’ phase is considered. The diversity of vessel components that could contribute to the spread of NIS suggests that a focus on external hull fouling alone could lead to other potential mechanisms being overlooked. Even though the role of many of these other mechanisms is not well described, there is sufficient evidence to highlight their potential importance in certain situations. Thus, there is a need for further research and assessment of the potential for each of these components and their related events to entrain, transport, and release NIS from one environment into another. However, absence of such knowledge should not preclude recognition by managers of these diverse components as potential sources of recreational vessel risk. The model described here is a comprehensive conceptual representation of the invasion process via recreational boating. Thus, the model is a starting point for scientists and managers to reach consensus on this process, modify the components according to the specific attributes of different situations, and identify key uncertainties and information needs for quantitative risk assessment.

Chapter 3: Recreational boating and spatial management prioritisation

3.1 INTRODUCTION

Marine recreational boating has become increasingly popular in coastal areas of most developed countries, increasing the demand for coastal structures (e.g., marinas, wharves) associated with this activity (Lloret et al. 2008, Paoli et al. 2008). A number of negative effects on coastal and marine environments from recreational boating are recognised (Widmer and Underwood 2004), including littering (Backhurst and Cole 2000), sewage discharge (Guillon-Cottard et al. 1998), biocide pollution from antifouling paints (Rilov et al. 2000), and physical damage to organisms and habitats (Milazzo et al. 2004, Hazel and Gyuris 2006).

Recreational vessels have also been identified as key vectors for the introduction and spread of non-indigenous species (NIS), especially at a regional scale (e.g., Hewitt and Campbell 2001, Floerl et al. 2005a, Ashton et al. 2006a, Dijkstra et al. 2007, Mineur et al. 2008, Acosta and Forrest 2009, Darbyson et al. 2009, Davidson et al. 2010). The movement of recreational vessels between coastal structures, such as marina berths and moorings makes such structures likely to be infection (incursion) nodes for NIS introduction (Kinloch et al. 2003, Sinner et al. 2009) and important reservoirs for the potential spread of such NIS (Bax et al. 2002, Glasby et al. 2007).

Marine NIS are recognised as a leading cause of environmental degradation and biodiversity loss (Vitousek et al. 1997, Carlton 2000, Bax et al. 2003, Byrnes et al. 2007 Briggs 2012), with a range of potential and realised ecological impacts documented in coastal and marine ecosystems worldwide (e.g., Meinesz et al. 1993, Ruiz et al. 2000a, Williams and Smith 2007, Dittel and Epifanio 2009, Burfeind et al. 2012). NIS impacts are often long-lasting and can translate into economic losses (Pimentel et al. 2000, 2005, Cacho 2006, Carrasco et al. 2010), especially when commercial values such as fisheries and aquaculture are affected (Colautti et al. 2006). For example, recreational boating is a likely pathway for the invasive clubbed tunicate *Styela clava* (Minchin 2007b, Gust et al. 2008, Darbyson et al. 2009, NIMPIS 2013). This NIS presents an important economic and operational burden to shellfish aquaculture in the United States and Canada (Bourque et al. 2005, Karney and Rhee 2009).

Management of NIS is therefore essential to ensure protection and conservation of coastal and marine ecosystems and their associated commercial values. Given the difficulties inherent in controlling established populations of pest species, such management is likely to be more effective and efficient using a preventative approach that aims to manage the pathways by which NIS are spread (Leung et al. 2002, Floerl et al. 2005c, Wittenberg and Cock 2005, Christy et al. 2007).

Profiling of pathway risks and evaluation of management options has been an integral part of marine NIS research, with considerable attention initially focused on ballast water and hull fouling from commercial shipping (e.g., Carlton 1985, Ruiz et al. 1997, Gollasch 2002, Drake and Lodge 2004, McGee et al 2006, DiBianco et al. 2011). More recently, increasing evidence for the role of recreational boating as a spread mechanism for NIS at a range of spatial scales (e.g., Wasson et al. 2001, Floerl et al. 2005a, Ashton et al. 2006a, Mineur et al. 2008, Floerl et al. 2009, Davidson et al. 2010, Lacoursière-Roussel et al. 2012) has driven more research and management of this pathway (e.g., Lambert and Lambert 2003, Dijkstra et al. 2007, Acosta and Forest 2009, Kondilatos et al 2010, Bell et al. 2011, Clarke Murray et al. 2011). Despite this, risk assessment and management frameworks for recreational boating as a NIS pathway are still limited, especially in New Zealand (e.g., Sinner et al. 2009, Floerl et al. 2010a, Bell et al. 2011).

This chapter describes a methodology to: 1) analyse recreational boating as a regional pathway for marine NIS, and 2) rank different locations based on their importance as components of this pathway and potential NIS spread within the study region. The methodology was developed based on the systematic analysis framework and risk priority number (RPN) concept used by the hazard identification and assessment methodology, Failure Mode and Effect Analysis (FMEA) (Jordan 1972).

The methodology developed here was used to characterise and assess the recreational boating pathway and its components in the New Zealand coastal region encompassed by Golden Bay and Tasman Bay (Fig. 1.2). This region has two important marinas and smaller vessel transport hubs (Chapter 1), which have been recognised for their potential role in regional spread of marine NIS, particularly due to aquaculture associated operations (Chapter 4), natural coastal currents (Chapter 5), and recreational boating activities (McClary and Stuart 2004, Piola and Forrest 2009, Hayden et al. 2009, Lacoursiére-Roussel et al. 2012). The study region also covers a range of areas with environmental, socio-cultural, economic and/or Māori significance values, which could be threatened by the introduction and further spread of NIS (Morrisey and Miller 2008, Piola and Forrest 2009, Section 1.4).

The results of the analysis using this new methodology highlight recreational boating as a potentially important NIS pathway for this region. These results could be used to prioritise the likelihood of NIS spread across different coastal areas, and thus, improve management of this pathway. The simplicity of the data required and the straightforward implementation of the method suggest that this approach could be easily applied to analyse recreational boating pathways elsewhere. It could also be modified to analyse other human-mediated pathways for NIS.

3.2 METHODS

3.2.1 Failure Mode and Effect Analysis (FMEA)

FMEA is a well-known hazard identification and assessment technique commonly used to eliminate or minimise the risk associated with potential design and process failures before their occurrence (Franceschini and Galetto 2001, Burgman 2005). To date, several variations of the FMEA methodology have been widely used to identify, prioritise and eliminate potential failures, problems and errors from systems in several fields such as the automotive (e.g., Cherry and Jones 1995) and aerospace (e.g., Price et al. 1997) industries, nuclear power generation (e.g., Burgazzi 2005), medical device manufacture (e.g., Wood and Ermans 1993), and hardware and software production (e.g., Kenyon and Newell 1983).

The use of FMEA in the environmental and natural resources management remains rare (Burgman 2005), with limited examples in this area. For instance, (Hayes 2002a), developed the Infection Mode and Effect Analysis (a variation of the FMEA), which was used in south-eastern Australia to categorise and prioritise the components of some working and recreational vessels in the transport of marine NIS between locations. The same approach was used in New Zealand to rank the risk of *S. clava* dispersing to high value areas (Gust et al. 2008). Similarly, the FMEA approach was used in Ireland to assess the component of different leisure vessels as vectors for the spread of the zebra mussel *Dreissena polymorpha* (Minchin et al. 2006b).

FMEA for industrial systems is usually comprised of the following six consecutive steps (Stamatis 1995):

1. Identification of all components,
2. Identification of all failure modes, considering all possible operating modes,
3. Identification of the potential effects of each failure mode, scoring their severity,
4. Identification of the potential causes of each failure mode, scoring their likelihood of occurrence,
5. Identification of current controls to prevent the failure mode, scoring the likelihood of detection, and
6. Calculation of the Risk Priority Number (RPN).

The RPN is defined as the product of factors Severity, Occurrence, and Detection, which are estimated during steps 2–5.

$$RPN = Severity * Occurence * Detection \qquad \text{Equation 3-1}$$

Severity is an assessment of the seriousness of the effect of the failure, Occurrence is the assessment of the likelihood of a specific cause leading to a failure mode during a pre-determined time frame, and Detection is the likelihood that the cause of the failure, or the failure itself, will be detected, thus preventing failure (Stamatis 1995, Burgman 2005). The RPN is calculated for each component and failure mode in the system. The final output of the FMEA is a list of RPNs that is used to set priorities for actions on hazards and to identify components that require attention. Components with higher RPNs should be the focus of improvements, which are usually aimed at lowering Severity and Occurrence (Stamatis 1995, Burgman 2005). However, adding verification controls can increase the likelihood of detecting failure thus reducing the final RPN.

3.2.2 FMEA and recreational boating

The structured and systematic approach of FMEA, as well as its concept of a priority number (i.e., RPN) for comparison and ranking of different components was used as a framework to analyse recreational boating as a pathway for the spread of NIS within the study region. The specific approach followed four consecutive steps:

1. Components and processes identification,
2. Pathway modelling,
3. Management unit definition, and
4. Management unit priority value calculation.

3.2.3 Components and processes identification

The components and processes of the recreational boating pathway in Golden Bay and Tasman Bay were identified and characterised based on: 1) local marine facilities, 2) resident recreational vessels, and 3) boating habits within this region. Although some information (e.g., marine facility types and locations) was available from sources such as governmental agencies (i.e., Tasman District Council, Nelson City Council, and Marlborough District Council), yachting publications (e.g., Murray and von Kohorn 2002), and Google imagery (http://maps.google.co.nz), it was essential to conduct a survey among recreational vessel users in the study region to collect and generate accurate information of this pathway.

The survey was conducted in June–July, 2004. An initial questionnaire was designed based on: 1) general literature on recreational boating as a NIS pathway (e.g., Floerl 2002, Hayes 2002a, Kinloch et al. 2003), 2) the author's knowledge of recreational vessels, and 3) informal conversations with recreational vessel users. The questionnaire was pre-tested (Meyer and Booker 1991, Ayyub 2001) with five local recreational vessel users, five non-local recreational vessel users (i.e., Westhaven marina, Auckland) and 10 lay people. The answers and feedback from these tests were used to improve the questionnaire. The five local recreational vessel users, who participated in this trial, were not included in the survey in order to prevent potential biases due to their prior familiarity with the questionnaire.

The final questionnaire comprised four sections and totalled 29 questions (Appendix B.1). The first section focused on the characteristics of the vessels (e.g., vessel type, dimensions). The second section asked about the frequency of usage of the vessel in the study region and activities conducted (e.g., recreation, racing) and marine facilities visited (e.g., marinas, wharves, boat ramps). The third and fourth sections dealt with maintenance habits and areas visited within the study region, respectively. Direct, short, closed-ended, and where possible multiple choice, questions were used (Salant and Dillman 1994, Weisberg et al. 1996). The last question included two maps on which respondents had to indicate their usual cruising routes in November–March (i.e., summer) and in April–October (i.e., the rest of the year). The survey was approved by the Auckland University of Technology Ethical Committee (Reference AUTEC 1028).

Recreational vessels in New Zealand are not required to be registered, so it is difficult to: 1) accurately estimate the total number of resident vessels within a specific region, and 2) reach their users/operators to collect information on boating habits. The survey was therefore restricted to vessel owners/users registered at either the Tarakohe marina, the Nelson marina or one of four cruising and yachting clubs operating in the study region (i.e., Motueka Yacht and

Cruising Club, Nelson Marlborough Yachting Association, Nelson Yacht Club, and Tasman Bay Cruising Club).

Most of the questionnaires were mailed out directly by the author, but in some cases, it was the club or manager of the marinas who distributed them due to their confidentially agreements. Hence, the precise number of questionnaires delivered could not be determined, but it is estimated that at least 700 questionnaires were sent out. The actual number of people reached is estimated to be considerably less. This is because it is common for some moored vessels to be on the mailing list of both a marina and a yachting club (G. Stricker pers. comm., pers. obs.). In order to maximise the response rate an incentive was used (Hare et al. 1998) and a post-paid return envelope was included. The local paper, *The Nelson Post,* also published an article featuring the survey and invited recreational boat users to participate in it.

3.2.4 Pathway modelling

An initial comprehensive model, integrating the components, variables and processes of NIS spreading through recreational boating, was developed based on all the collated information (Chapter 2). The complexity of this model and the spatio-temporal dependency of many of its variables made it highly specific and thus, impractical for analysis at a regional scale. Thus, the model was simplified by examining the pathway at a broader resolution (i.e., considering vessel risk overall, rather than risk for separate vessel components, such as hull fouling, deck, bilge water, etc.). The final components and processes considered can be summarised in the following sequence of events (Fig. 3.1):

1. Vessel V entrains NIS S, which is present in the environment of marine facility X, when visiting this facility,
2. NIS S is transported by vessel V from the environment of marine facility X to the environment of marine facility Y along cruising route X↔Y, and
3. Vessel V releases NIS S into the environment of marine facility Y when visiting this facility.

As indicated in this conceptual model, the present study considered NIS spread as the three-step process of: 1) entrainment (event 1), 2) translocation (event 2), and 3) release (event 3). Similarly, the recreational boating pathway was modelled as the three-component system of: 1) vessels, 2) marine facilities, and 3) cruising (connecting) routes (Fig. 3.1). Marine facilities in the model were restricted to seven specific types that vessel users reported visiting/using across the region (see section 3.3).

3.2.5 Management unit definition

Direct quantification of the three steps of the NIS spread process via recreational vessels (i.e., entrainment, transport, and release) in the study region based on available data was considered difficult and unrealistic. Conversely, quantification of marine facilities, vessels and cruising routes (i.e., system components) appeared a more plausible option, although with a considerable level of uncertainty. The present study used the components of the pathway instead of its processes to assess recreational boating as a spread mechanism for marine NIS.

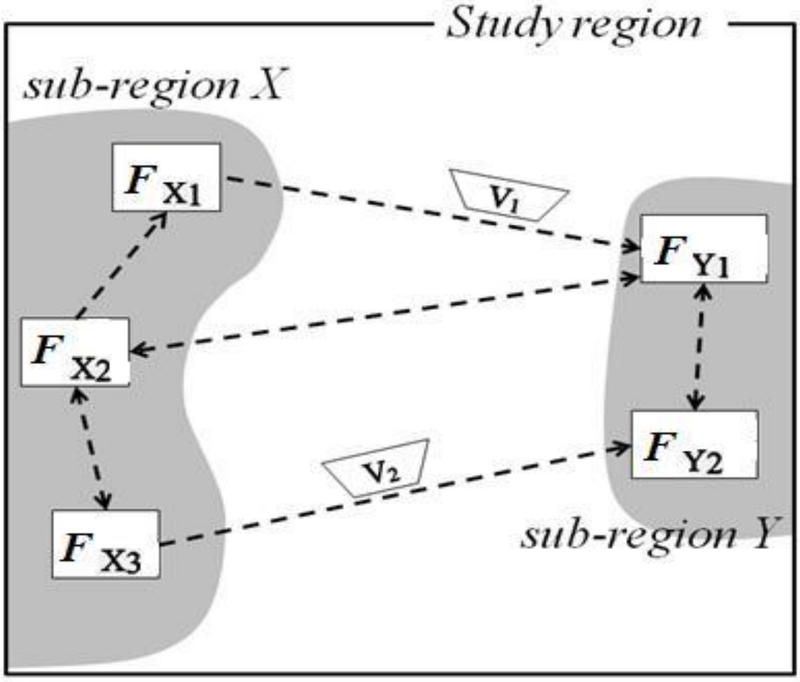

Figure 3.1 Basic conceptual model of NIS spread via recreational boating. Recreational vessels (V_1: moored, V_2: trailered) connect via cruising routes (--->) different marine facilities (*F*) and sub-regions.

Each component of the system was characterised based on its role in the NIS spread process. The likelihood of NIS spread via recreational vessels is specific to the species and vessel component (e.g., Hayes 2002a, Minchin et al. 2006b, Hayes et al. 2007, Darbyson et al. 2009, Chapter 2), but in order to produce a more general model and simplify the analysis, no distinction was made among vessel components, and the entire vessel was considered to be a single vector of spread. Similarly, the likelihood of NIS spread by vessels that spend most of the time (e.g., greater than 80% of the year) in the water (i.e., moored vessels) is considerably higher (at least in terms of hull fouling) than for those that are trailered and not kept in the water (Minchin et al. 2006b, Hewitt et al. 2009). Taking this into account, vessels were divided into: 1) moored and 2) trailered. A larger number of visiting vessels means a higher probability of NIS arrival (i.e., higher 'propagule pressure'; Williamson 1996, Lockwood et al. 2005, Colautti et al. 2006, Leung and Mandrak 2007, Lockwood et al. 2009). Hence, the frequency of use of connecting routes and costal habitats was considered in the model.

The initial three-component conceptual system (i.e., vessels, marine facilities, and routes) was a basic, but practical approach that could integrate the limited available data to model recreational boating as a marine NIS pathway. However, the value of this model's components as management units was restricted by three factors. Firstly, the spatio-temporal variation associated with these components would make using fine spatial resolution (e.g., specific marine facility and cruising routes) impractical. For example, although a vessel might always visit the same coastal zone, the specific site(s) and marine facilities used would depend on factors such as the weather and purpose of each trip (e.g., Wilderman and Underwood 2004). Secondly, the level of detail used to indicate their cruising habits was not the same among all the respondents to the survey: while some clearly indicated the specific location and structure usually visited by their vessels (e.g., 'TBD mooring in Torrent Bay', 'Motueka wharf') others only indicated the area (e.g., 'Abel Tasman National Park', 'Croisilles Harbour'). Thirdly, even in an ideal scenario with no variation and the required data available, using such a fine scale model would be impractical for management at a regional scale. Hence, in order to have a model component which could be used as a management unit, the entity 'sub-region' was created.

This spatial entity sub-region, defined by the cruising patterns identified in the survey, allowed the model to: 1) avoid the problem of data with variable resolution (e.g., because of different levels of detail reported by survey respondents), 2) provide an adequate and practical scale for regional analysis, and most importantly, 3) use a single management unit, which considered all the components of the system to assess the NIS pathway. The recreational boating pathway in the study region was therefore conceived as a network of 11 sub-regions (nodes) interconnected by two sets of connecting routes (links), resulting from the cruising patterns of moored and trailered vessels, respectively (see results). This modified the conceptual sequence of events of the NIS spread process as follows (Fig. 3.1):

1. NIS S, which is present in sub-region X (origin node), is entrained by the recreational vessel V_1 when visiting marine facility X_i (entrainment),
2. Vessel V_1 transports NIS S into sub-region Y (destination node) along the connecting route X↔Y (link), and
3. NIS S is released in sub-region Y when vessel V_1 visits marine facility Y_i (release).

3.2.6 Management unit and the Priority Ranking Value

In order to have a comparative value that facilitates prioritising of management options among areas, the 'Priority ranking value' (PRV) was calculated for each of the 11 sub-regions. PRV_{Si} was defined based on the probability of sub-region *i* receiving/dispersing NIS from/into other sub-regions by recreational vessel traffic (i.e., the spread potential of the sub-region).

The NIS spread potential of a particular sub-region via recreational vessels is proportional to its frequency of being visited and its connectivity with other sub-regions (Kinloch et al. 2003, Floerl et al. 2009, Hewitt et al. 2009). The more visited and better connected sub-region *i* is within the network of sub-regions, the higher its probability of becoming infected and becoming a NIS source for other sub-regions. However sub-regions are simply a spatial unit encompassing a number of specific facilities, and the interaction between connecting routes and sub-regions occur through these facilities (Figs. 3.1). As such, the sub-region PRV was initially defined in this study as the sum of the PRV of each of the marine facilities within the sub-region that could potentially be visited by recreational vessels, and represented as:

$$PRV_{S_i} = \left(\sum_{j=1}^{n} PRV_{F_j} \right) \qquad \text{Equation 3-2}$$

where PRV_F refers to the PRV of a facility, the subscript *j* indicates the specific facility considered and *n* the total number of facilities present in sub-region *i*. The PRV for each facility *j* was, in turn, defined as:

$$PRV_{F_j} = PU_{F_j} * PI_{F_j} \qquad \text{Equation 3-3}$$

with PU_{Fj} representing the probability of facility *j* being used by recreational vessels and PI_{Fi} the probability of facility *j* becoming infected. In reality, the individual patterns of use of the structures, as well as their individual probability of infection, were unknown. It was therefore necessary to assume that facilities of same type (e.g., marinas, boat ramps) had the same probability of use, and a similar probability of infection. The probability of infection was estimated based on expert opinion gathered through the elicitation exercise described in section 3.2.7. As the probability of using a particular facility would still be determined by the probability of recreational vessels visiting the sub-region where that facility is located, the relative usage probability of each facility was defined in this study as:

$$PU_{F_j} = PV_{Si} * PV_{F_X} \quad \text{Equation 3-4}$$

where PV_{Si} is the probability of recreational vessels visiting sub-region *i* and PV_{Fx} the probability of recreational vessels using a facility type *x* (e.g., marina, wharf) in the study region. These values were obtained from the survey as the percentage of vessels visiting each sub-region and the percentage of vessels using each facility type; both expressed as a probability value between 0–1.

As indicated before, the connectivity influences the probability of a sub-region receiving/dispersing NIS within the study area (Kinloch et al. 2003, Floerl et al. 2009). To account for this, the 'Connectivity ranking value' (CR), a new connectivity measure suggested here, was developed and included in equation 3.2 as a multiplying factor:

$$PRV_{S_i} = \left(\sum_{j=1}^{n} PRV_{F_j} \right) * CR_{S_i} \quad \text{Equation 3-5}$$

This new connectivity measure was defined as:

$$CR_{Si} = \left(\sum_{j=1}^{m} {CV_{ij}}/{ICV_{ij}} \right) * {ac}/{pc} \quad \text{Equation 3-6}$$

where subscript *i* indicates the sub-region under assessment, subscript *j* the connecting sub-region and *m* represents the total number of sub-regions that could be connected to sub-region *i*. CV_{ij} is the connectivity value between sub-region *i* and *j*, defined as the percentage of vessels reported to be travelling directly between these sub-regions. ICV_{ij} is the CV_{ij} under an ideal spread scenario, which in this particular case was considered to be 100% in all connections (i.e., all vessels use all links). Variable *ac* in the equation refers to the actual number of connections, while *pc* refers to the total number of connections in an ideal scenario.

As each sub-region could be potentially connected to 10 sub-regions via 10 direct connections, *m* and *pc* were a constant of 10 in both vessel types. CR takes into account both the number of connections with other sub-regions and more importantly, the efficiency of each connection. CR also includes the 'ideal' spread scenario as a normalising factor, which makes comparisons and ranking easier.

Cruising time between areas can affect the trip survival of some NIS species (e.g., macroalgae (Flagella et al. 2007)) and thus, their success of spread via vessels. In the study region the largest direct cruising distance is just over 100 km, implying that it would take less than 11 hr to travel between sub-regions even on a slow recreational vessel (i.e., average cruising speed of 5 knots). It has been observed that specimens of invasive species, such as *Undaria pinnatifida* (Forest and Blakemore 2006) and *S. clava* (Darbyson et al. 2009) survive relatively long periods (>1 day) out of the water (e.g., on deck, fishing gear). The author assumed that travel differences of only a few hours will have little bearing on the survival of NIS associated with a vessel, especially when referring to hull biofouling (e.g., Gollasch and Riemann-Zuerneck 1996, Apte et al. 2000), such that it was unnecessary to include distance in the calculations.

The present study, as well as the mail survey and expert elicitation exercise, differentiated between moored and trailered vessels. Similarly, it differentiated between summer (November–March) and the rest of the year, mainly because of the well-known (and contrasting) disparity between these periods regarding the use of recreational vessels in New Zealand. Hence, four PRV were calculated for each sub-region: 1) two PRV using the results for moored vessels (summer and rest of the year), and 2) two PRV using the results for trailered vessels (summer and rest of the year). In order to make comparisons easier, the resulting PRV were normalised by the maximum PRV obtained and multiplied by 100, scaling them to 0–100.

All the tabular answers of the mail questionnaire were integrated in a database using Microsoft ACCESS 2002. Similarly, all cruising lines drawn on the questionnaires were digitised and integrated into a geographical information system (GIS) using ArcGIS v. 8.3. The database and GIS were linked using the vessel ID as the shared attribute. Several spatial and tabular queries were designed to synthesise and analyse the information provided in the questionnaires. Statistical analyses were performed using MINITAB® Release 14.1 and the Open–source software R version 2.13 (R Development Core Team 2008)

3.2.7 Expert probability of infection

Expert opinion was used to generate estimates of the probability of infection of marine facilities within Golden Bay and Tasman Bay via recreational vessels. Expert data were generated through two elicitation exercises (sent by email) following a Delphi approach (Dalkey 1969, Linstone and Turoff 1975, Parenté and Anderson-Parenté 1987). The first exercise was used to develop a conceptual model for marine invasions via recreational vessels (see for details Chapter 2). The second exercise was used to share the feedback collected in the first exercise so experts could improve the conceptual model. In this exercise, experts were also asked to estimate the probability of infection of seven marine facilities (selected from the recreational boating survey) via moored and trailered vessels (Appendix A.3).

As indicated in section 1.4, most of the western area of the study region is exposed to tidal desiccation during low tide. This implies that vessels at marine facilities within this area during low tide are in direct contact with the intertidal seabed, which can have an effect on the likelihood of releasing hull biofouling from these vessels into the environment (McClary and Stuart 2004, Chapter 2). Therefore, the exercise differentiated between intertidal and subtidal anchorages[8], marinas, moorings, and wharves. Intertidal marine farms were not considered as most of the marine aquaculture within Golden Bay and Tasman Bay is Greenshell™ mussel (*Perna canaliculus*) related (i.e., subtidal marine farms).

Five specific aspects were considered in this process to improve the accuracy of experts' judgement, reduce the uncertainty in the generated data, and model this uncertainty throughout the analysis. Firstly, each questionnaire (including a cover letter explaining the aim of the exercise and the methodology to follow) was tested with groups of at least five people before being sent to the experts (Meyer and Booker 1991). Secondly, specific baseline information was included at the beginning of the exercises so that all the experts had a common knowledge and understanding of the issues considered (Clemen and Winkler 1999, Ayyub 2001). Thirdly, technical terms and words with unclear or potentially confusing meanings were clearly defined to prevent ambiguity (Regan et al. 2002, Burgman 2005) and definitional disagreements (Clemen and Winkler 1999). Fourthly, after giving an initial estimate, experts were required to think about one reason that could 'make it wrong' (i.e., disconfirming information) and decide whether this would lead them to change their answer (Morgan and Henrion 1990, Chhiber et al. 1992). Finally, and most importantly, experts had to indicate their assessments of probability through simple and commonly used words.

Experts were required to indicate their probability estimates in a linguistic form, selecting from the terms: 1) Very unlikely, 2) Unlikely, 3) Likely, or 4) Very likely (Acosta et al. 2010). The final section of the exercise asked experts to consider the scenario where 'a man reaches into a bag of 100 golf balls, that could be painted white or blue, and without looking grabs one', and state the minimum and maximum number of blue balls that should be in the bag for them to consider the probability of the man randomly choosing a blue ball as: 1) Very unlikely, 2) Unlikely, 3) Likely, and 4) Very likely (Acosta et al. 2010). An example of a possible answer was presented, but in order to prevent anchoring (i.e., the tendency to provide subjective assessments or values similar to one(s) already proposed (Slovic and Lictenstein 1971, Tversky and Kahneman 1974, Block and Harper 1991) with this example the term 'remote' was used instead of any of the four probability terms applied in the exercise. This section gave an indication of the 'natural scale' each respondent associated with these words, and thus, allowed the use of fuzzy logic (Zadeh 1965), in particular interval type–2 fuzzy logic (IT2FL, Mendel 2001) to combine and analyse their answers (Appendix B.2).

Four steps were used to average the range of answers given for each probability term (Acosta et al. 2010, Appendix B.2). Firstly, the value ranges given for each word by participants were integrated using the Interval Approach (Liu and Mendel 2008). This defined a representing interval type–2 fuzzy set (IT2FS) for each word, achieving both fuzzification and encoding. Secondly, all the probability answers (i.e., words) were replaced by their representing IT2FSs. This not only made computation of different words possible, but also incorporated into the analysis the uncertainty arising from perception differences among participants about linguistic term meanings (Mendel 2003). Thirdly, the answers for each

[8] Anchorages are not marine facilities *per se* (no artificial structures are associated withthem) but were included under this category for simplicity.

question (now represented as IT2FS) were averaged using the Linguistic Weighted Average (LWA, Wu and Mendel 2007). In this case, all respondents were considered to be equally important in the survey, so their answers were equally weighted. Finally, the Jaccard similarity measure (Wu and Mendel 2009a) was used to classify the resulting IT2FS as one of the four probability words (i.e., Very unlikely, Unlikely, Likely, and Very likely). The result was simultaneously decoded as the word with the maximum Jaccard similarity and defuzzified (turned into a 'crisp value') using the Enhanced Karnik-Mendel algorithm (Wu and Mendel 2009b). This algorithm converts the IT2FS into an interval type–1 fuzzy set identifying its characterising left– and right–end points ([Cl , Cr]) (Wu and Mendel 2009a). Details of fuzzy sets and these calculations, as well as an example of the procedures followed to combine the answers of the experts, are presented in Appendix B.2. All fuzzy logic analyses were conducted using the Open–source software QtOctave (www.ohloh.net/p/qtoctave).

3.2.8 Statistical analyses

Several statistical tests were used to analyse the results from the recreational boating survey and the expert elicitation exercise. The one-way ANOVA test was used to investigate monthly variation during the year (and thus seasonal pattern) of recreational boating activity in the study region. The ANOVA assumptions of normality, independence, and homogeneity of variances were previously investigated with several plots (e.g., histograms), descriptive statistics (e.g., mean, standard deviation, variance, skewness and kurtosis), the Shapiro-Wilk test and the Levene's test.

Relationships between vessel types and activities, as well as cleaning seasonality, were analysed using the Chi square test. This test was also used to analyse the number of moored vessels and trailered vessels visiting each sub-region. When the sample size was not large enough to apply this test, the Fisher's exact test was conducted instead. Differences between PRV values of sub-regions, between summer and the rest of the year, and between moored and trailered vessels were analysed using the tests Mann-Whitney U Test and Wilcoxon Matched-Pairs Signed-Ranks. Variability in IT2FSs was calculated via the uncertainty of the IT2FS, defined as the distance between the characterising left– and right–end points ([Cl , Cr]) of the resulting interval T1FS (Wu and Mendel 2009a) (Appendix B.2).

3.3 RESULTS

3.3.1 Expert elicitation exercise

3.3.1.1 Participating experts

Although all the people who answered the first elicitation exercise (see Chapter 2) were provided with the second elicitation exercise, only six out of fourteen returned it completed. One of these experts updated all the estimates to 'Very unlikely' but expressed that 'the extremely high uncertainty associated with such processes prevented him from being happy with any given estimates'. Therefore, the results from this expert were not included in the final analysis, which left only five participating experts. All participating experts had experience in recreational boating, but only some had previously worked in the fields of marine invasions (3 experts), risk assessment (2 experts), and biosecurity management (3 experts) (see for details Table 2.3).

3.3.1.2 Probability terms

As expected, the terms Very unlikely, Unlikely, Likely and Very likely had different (numeric) meanings for the experts (Table 3.1). The highest variation was observed in the upper limit (lower limit) of Likely (Very likely) and in the lower limit (upper limit) of Likely (Unlikely). Consequently, the uncertainty (Cr– Cl) associated with the terms Likely and Very likely (and respective IT2FS) was also the highest, with values of 0.1 and 0.22, respectively (Table 3.1).

Table 3.1 Expert probability terms. Numeric ranges given by five experts on recreational boating to the terms Very unlikely, Unlikely, Likely and Very likely. Experts indicated their answers in percentage, which were then scaled between 0–1. Results based on a two-round elicitation exercise conducted between October 2010–August 2011. The uncertainty value represents the variability associated with the interval type–2 fuzzy sets representing each expert linguistic term generated using the Interval Approach and the elicited lower and upper limits. The uncertainty was calculated as the difference between the left- and right-end points (Cl and Cr) of the resulting interval type–1 fuzzy set of the probability terms. SD = standard deviation.

	Probability term							
	Very unlikely		Unlikely		Likely		Very likely	
Expert	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
1	0	0.1	0.1	0.5	0.5	0.9	0.9	1
2	0	0.01	0.01	0.1	0.1	0.5	0.5	1
3	0	0.05	0.05	0.2	0.2	0.8	0.8	1
4	0	0.05	0.05	0.15	0.15	0.5	0.5	1
5	0	0.1	0.1	0.2	0.2	0.6	0.6	1
$\tilde{x}$	0	0.06	0.06	0.23	0.23	0.66	0.66	1
SD	0	0.04	0.04	0.16	0.16	0.18	0.18	0
Uncertainty (Cr-Cl)	0.06		0.05		0.1		0.22	

3.3.1.3 Infection probability estimates

Following the structure of the exercise, the experts had the opportunity to update the initial estimates after thinking about a possible situation that could make each estimate wrong. All experts updated more than 25% of their initial answers. The final experts' estimates for the probability of infection of marine facilities via moored vessels varied between Likely and Very likely, with crisp values (CA) between 0.29 (subtidal wharves) and 0.84 (subtidal marinas) (Table 3.2, Fig. 3.2). Intertidal mooring areas (0.75) and marinas (0.68) also showed comparatively higher probability of infection in moored vessels. Higher probabilities of infection were associated with higher uncertainty values.

Conversely, most of the estimates for trailered vessels were classified as Likely, except subtidal anchorages and marinas and marine farms that were classified as Unlikely. The highest probability of infection with trailered vessels was for boat ramps (0.4), slipways (0.39) and intertidal moorings (0.39), while subtidal anchorages, marinas and marine farms had the lowest probability (all values of 0.17). As with moored vessels, higher infection probabilities showed higher uncertainty values (Table 3.2, Fig. 3.2).

Table 3.2 Expert estimates for the probability of infection of marine facilities in the study region. LWA= Linguistic weighted average of the answers of five experts when asked how likely it was for the indicated marine facilities to become infected when visited/used by recreational vessels. CA= Centroid of the resulting interval type–2 fuzzy set (IT2FS), which represents the crisp value of the estimated linguistic probability. The uncertainty of the estimated probability was calculated as the difference between the left- and right-end points (Cl and Cr) of the resulting interval type–1 fuzzy set of the probability estimates (i.e., IT2FS).

Vessel type	Location	Tidal exposure	Expert					Probability of infection		Uncertainty
			1	2	3	4	5	LWA	CA	(Cr–Cl)
Moored	Anchorages	Intertidal	L	L	Vl	Vl	L	Likely	0.55	0.14
		Subtidal	Vl	Vl	Vl	L	L	Very likely	0.65	0.16
	Wharves	Intertidal	L	L	U	Vl	L	Likely	0.40	0.11
		Subtidal	L	L	U	L	L	Likely	0.29	0.09
	Moorings	Intertidal	Vl	Vl	Vl	Vl	L	Very likely	0.75	0.19
		Subtidal	Vl	Vl	Vl	L	L	Very likely	0.65	0.16
	Boat ramps	Intertidal	L	L	Vu	Vl	Vu	Likely	0.32	0.10
	Slipways	Intertidal	L	L	Vl	Vl	Vl	Very likely	0.65	0.16
	Marinas	Intertidal	Vl	Vl	Vl	Vl	Vu	Very likely	0.68	0.19
		Subtidal	Vl	Vl	Vl	Vl	Vl	Very likely	0.84	0.23
	Marine farms	Subtidal	Vl	L	Vu	L	L	Likely	0.39	0.11
Trailered	Anchorages	Intertidal	L	L	Vu	L	U	Likely	0.23	0.08
		Subtidal	L	L	Vu	U	U	Unlikely	0.17	0.07
	Wharves	Intertidal	L	U	U	U	L	Likely	0.18	0.07
		Subtidal	L	U	U	L	L	Likely	0.24	0.08
	Moorings	Intertidal	L	L	Vu	Vl	L	Likely	0.39	0.11
		Subtidal	L	L	Vu	U	L	Likely	0.23	0.08
	Boat ramps	Intertidal	U	L	L	L	Vl	Likely	0.40	0.11
	Slipways	Intertidal	L	L	Vu	L	Vl	Likely	0.39	0.11
	Marinas	Intertidal	L	L	Vu	L	U	Likely	0.23	0.08
		Subtidal	L	U	Vu	L	U	Unlikely	0.17	0.07
	Marine farms	Subtidal	U	L	Vu	L	U	Unlikely	0.17	0.07

The results for the Wilcoxon Matched-Pairs Signed-Ranks test showed that the difference in the estimated infection probability values between moored and trailered vessels was significant ($W+ = 64$, $W– = 2$, $N = 11$, $p \leq 0.05$). This test also showed a significant difference in the estimated probabilities of infection when comparing subtidal and intertidal facilities ($W+ = 20$, $W– = 16$, $N = 8$, $p \leq 0.05$) although there was no discernible general pattern (e.g., always higher CA in subtidal facilities) (Table 3.2, Fig. 3.2).

3.3.2 Recreational boating in the study region

A total of 340 questionnaires were received back from the survey but only 320 represented vessels that actually visit the study site at least once per year. Assuming the survey initially had reached 700 people (see section 3.2) this gives a response rate of 45.7%. As stated before, it is very likely that a vessel owner received more than one questionnaire, which would underestimate the response rate of the survey. Most of the questionnaires received were from keelers (37.7%), launches (17.7%) and small powered crafts (13.3%) (Table 3.3). Questionnaires from trailer yachts, motor cruisers and dinghies were also received but in lower numbers (< 11%). A total of 205 vessels (64.1%) reported to be permanently moored (i.e., > 80% of the year), while the other 115 (35.9%) reported to be trailered and launched at boat ramps or beaches (Table 3.3).

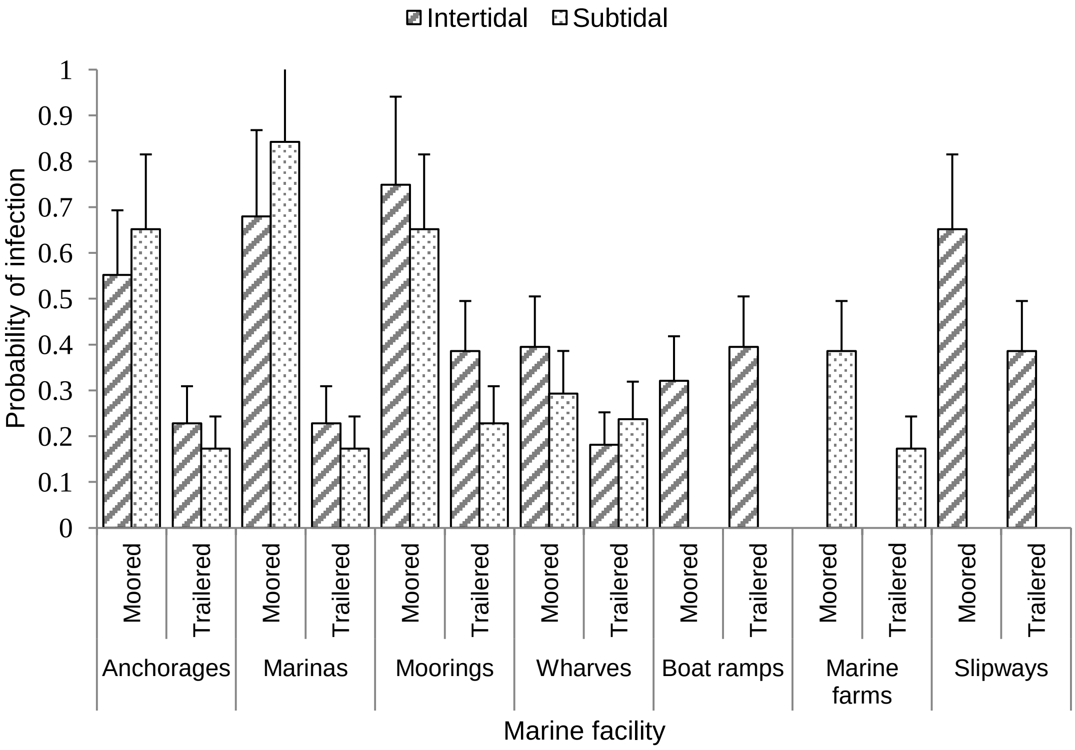

Figure 3.2 Expert probability of infection (+ uncertainty) for marine facilities in the study region. Probability calculated as the centroid of the resulting interval type–2 fuzzy set (IT2FS) from the linguistic weighted average (LWA) of the estimates given by five experts. The uncertainty of the estimated probability was calculated as the difference between the left- and right-end points of the resulting interval type–1 fuzzy set of the probability estimates (i.e., IT2FS).

Table 3.3 Type of vessels present in the study region. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

	Recreational vessels (%)		
Vessel type	Moored	Trailered	All
Keeler	58	0.9	37.5
Launch	27.3	–	17.5
Small powered crafts	–	37.4	13.4
Dinghy	–	31.3	11.3
Trailer yacht	0.5	28.7	10.6
Motor cruiser	4.9	0.9	5.6
Multi–hull	8.3	0.9	3.4
Barge	1.0	–	0.6
Other	–	–	–
Total	64.1	35.9	100

3.3.2.1 Seasonal pattern of use

The survey showed that both moored and trailered vessels were more likely to be used in the study region between November and March (one-way ANOVA, P < 0.05), indicating a seasonal component of behaviour and vector activity (Table 3.4, Fig. 3.3). In both groups however, some vessels (<10) appeared to be used consistently throughout the year.

Table 3.4 One-way ANOVA results for use of recreational vessels in the study region (days used vs. month). Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered). The analysis included the reported average number of days the vessel of the respondent was used in the study region each month (i.e., Appendix B, question 2.a) (Fig. 3.3). DF= Degrees of freedom. SS= Sum of squares. MS= Mean square. Adj= Adjusted.

Type	Source	DF	SS	MS	F	P
Moored	Month	11	14786.4	1344.2	35.06	<0.001
	Error	2448	93858.2	38.3		
	Total	2459	108644.5			
S= 6.192	R-Square =13.61%		R-Square (adj) = 13.22%			
Type	Source	DF	SS	MS	F	P
Trailered	Month	11	26155.8	2377.8	29.36	<0.001
	Error	1368	110792.8	81		
	Total	1379	136948.6			
S= 8.999	R-Square =19.10%		R-Square (adj) = 18.45%			

3.3.2.2 Marine facility used

Personal post-survey conversations with eight of the respondents revealed that recreational vessel users use the terms ‘wharf’ and ‘jetty’ interchangeably. Moreover, most of the vessels (68%) that selected ‘wharf’ as an answer also selected ‘jetty’. Hence, although technically these terms might have different meanings (see Glossary), in this study they were combined and analysed under the terms ‘wharf’.

Moored and trailered vessels reported using or visiting all the seven marine facilities considered in the study region: 1) anchorages, 2) boat ramps, 3) marinas, 4) marine farms, 5) moorings, 6) slipways, and 7) wharves (Table 3.5). However, the total number of vessels visiting each of the seven facilities varied between moored and trailered vessels. As expected, all moored vessels indicated visiting marinas and most trailered vessels (93.9%) indicated visiting boat ramps (Table 3.5). A trailered vessel that did not report using boat ramps, indicated ‘beaches’ as the usual launching sites. Anchorages and mooring sites appeared as the second and third most visited facilities in both vessel groups (Table 3.5).

3.3.2.3 Main activity

Recreational cruising (88.8%), followed by fishing (53.4%), was reported as the main use of both moored and trailered vessels (Table 3.6). There were vessels (80% trailered, 66.3% moored) however, that indicated more than one main activity (e.g., recreation–fishing, cruising–racing). The results of the $\chi 2$ tests for the relation vessel type–activity also suggest recreation and fishing as the main use of most vessel types in both groups (Appendix B.4).

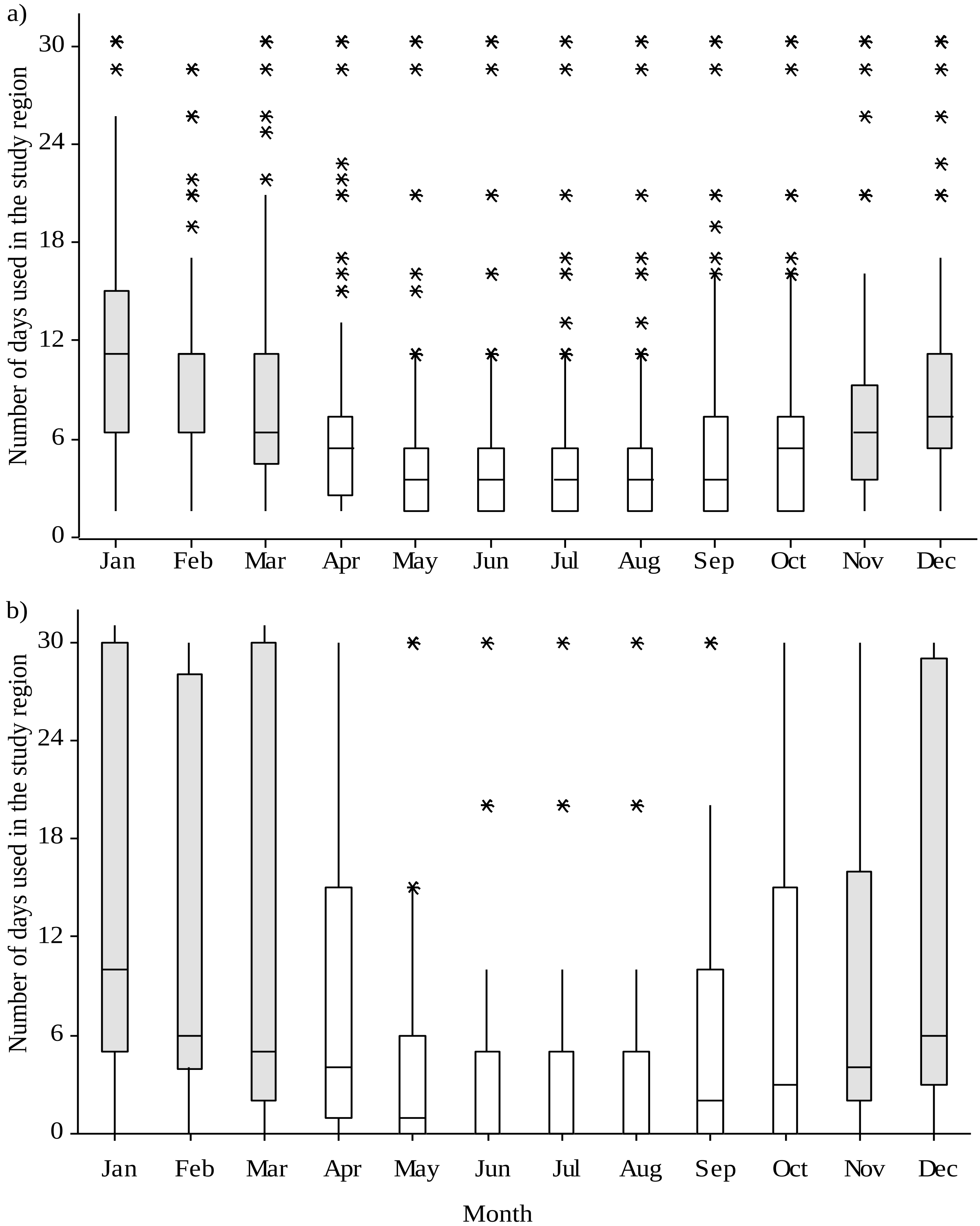

Figure 3.3 Usage frequency of recreational vessels in the study region. Box plots showing the mean number of days that a) Moored, and b) Trailered vessels are used in Golden Bay and/or Tasman Bay. Gray boxes represent summer. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

Table 3.5 Marine facilities reported to be visited by recreational vessels in the study region. PVF= Probability of recreational vessels using a marine facility (from Equation 3.4) expressed a value between 0–1. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

	Recreational vessels					
	Moored		Trailered		All	
Marine facility	%	PV_F	%	PV_F	%	PV_F
Anchorages	81	0.81	61.7	0.62	74.1	0.74
Boat ramps	4.9	0.05	93.9	0.94	36.9	0.37
Marinas	100	1	20	0.2	71.3	0.71
Marine farms	15.1	0.15	4.3	0.04	11.3	0.11
Moorings	48.8	0.49	23.5	0.23	39.7	0.4
Slipway	17.3	0.17	11.3	0.11	15.3	0.15
Wharves	35.1	0.35	26	0.26	31.9	0.32

Racing was also reported as a main activity for trailered vessels (38.3%) (Table 3.6). A small percentage of moored vessels were also reported to be used for marine farming (1.9%), ecotourism (1%), wildlife photography (0.6%) and sailing instruction (0.6%). Five moored vessels were reported to be used as homes. Similarly, 17.4% of trailered vessels were reported to be used for sailing instruction, 0.9% for marine farming and 0.9% for wildlife photography (Table 3.6).

Table 3.6 Marine activity conducted by recreational vessels in the study region. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

	Recreational vessels (%)		
Activity	Moored	Trailered	All
Recreation	91.7	83.5	88.8
Fishing	57.1	47	53.4
Diving	11.7	15.7	13.1
Charter	11.7	17.4	13.8
Transportation	10.2	21.7	14.4
Racing	9.8	38.3	20.0
Living	2.5	–	1.6
Marine farming	1.9	0.9	1.6
Ecotourism	1	–	0.6
Research	1	–	0.6
Sailing instruction	0.5	17.4	6.6
Wildlife photography	0.5	0.9	0.6
Recreation only	30.2	14.8	24.7
Fishing only	2.4	0.9	1.9
Racing only	1.0	3.5	1.9
Transportation only	–	0.9	0.3
More than one main activity	66.3	80	71.2
Recreation–Fishing	35.1	37.4	35.9
Recreation–Fishing–Diving	4.9	34.7	15.6

3.3.2.4 Fishing gear and bait type

Most of the moored and trailered vessels that reported fishing as one of their activities indicated fishing rods (85.7%) and dredges (65.1%) as the main fishing gear used (Table 3.7). The percentage of use of handlines (35%) by moored vessels and lines (25.9%) by trailered were also comparatively higher than other fishing gear. Only a low percentage of the vessels (< 12%) reported using either nets, trawls, pots/traps, or spearguns (Table 3.7). Similarly, most of the vessels use dead bait (73.7%). Out of 12 vessels that indicated having live wells, only one reported actually using them.

3.3.2.5 Sea chest and ballast water tanks

Only four moored vessels and one trailered vessel (an *Elliot 7.8*) reported having a sea chest of around 0.5 m^2. However, several respondents (i.e., 25 questionnaires) indicated that they were unfamiliar with the term 'sea chest'. Thus, it is likely that this survey underestimated the number of vessels with sea chests. Similarly, only two moored vessels and one trailered vessel (a *Young 6m*) indicated having a ballast water system.

Table 3.7 Fishing gear and bait type used by recreational vessels in the study region. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320. Total number of vessels used for fishing = 175 (117 moored and 54 trailered).

	Recreational vessels (%)		
Fishing gear	Moored	Trailered	All
Rod	92.3	77.8	85.7
Dredge	66.7	66.7	65.1
Handline	35.0	16.7	28.6
Net	11.1	11.1	10.9
Pot/Trap	9.4	3.7	7.4
Line	8.5	25.9	13.7
Trawl	5.1	1.9	4.0
Speargun	5.1	1.9	4.0
Bait used			
Only dead	83.8	57.4	73.7
Only live	–	–	–
Live and dead	13.7	24.1	16.6
No bait	2.6	13.0	5.7
No answer	2.6	1.8	2.9

3.3.2.6 Cleaning habits

Most moored vessels were reported to have had their hull cleaned below the waterline at least once per year (84.4%) and out of the water (67.3%) (Table 3.8). Only 15.1% of moored vessels were reported to have in-water hull cleaning, even when including vessels that reported cleaning both 'in and out of the water'. Haulout facilities were recorded as the main cleaning sites (76.6%) although some respondents indicated cleaning the hull of their vessels at boat ramps (14.1%), in the intertidal zone using tidal grids (12.7%), or at the beach (3.9%). October and November appeared as the most likely months for cleaning the hull of moored vessels in the study region ($\chi2$, $P < 0.05$, Table 3.9). The Nelson area was reported as the main cleaning location for these vessels.

As expected, most of the trailered vessels (90.4%) were reported to have their hulls cleaned (below waterline) 'each time they were taken out of the water' at boat ramps (61.7%) and homes (40%) (Table 3.8). The remaining trailered vessels (9.6%) were reported to be cleaned at least 'once per year'. When the cleaning is conducted at boat ramps, it is usually at the same launching boat ramp. Only two trailered vessels (1.7%) were reported to have their hull cleaned 'in and out of the water' (Table 3.8). Similarly, only four vessels (3.5%) were reported to conduct this cleaning at a haulout facility in the Nelson area.

Table 3.8 Hull cleaning (below waterline) frequency and location for recreational vessels in the study region. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

	Recreational vessels (%)	
Cleaning frequency	Moored	Trailered
Each time it is taken out	–	90.4
At least once per year	84.4	9.6
At least twice per year	15.6	–
Cleaning location		
In the water	2.9	0
Out of the water	81.9	98.3
In/Out of the water	15.1	1.7
Haulout facility	76.6	3.5
Tidal grids	12.7	–
Boat ramp	14.1	61.7
Beach	3.9	0.9
Home	0.5	40

Table 3.9 Chi-square test results for the number of recreational vessels cleaned in a particular month in the study region. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Only moored vessels (n = 205) considered in this test. Cont.= Contribution. DF= Degrees of freedom.

	Month													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Any	All
Count	13	21	25	17	13	14	16	13	29	40	53	33	23	310
Expected	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	23.8	*
Cont. to	4.9	0.3	0.05	1.96	4.9	4.0	2.5	4.9	1.1	10.9	35.6	3.5	0.03	
All	205	205	205	205	205	205	205	205	205	205	205	205	205	
Pearson $\chi2$ = 84.93, DF = 12, P <0.01 – Likelihood ratio $\chi2$ = 77.838, DF = 12, P < 0.01														

3.3.3 Management unit and prioritisation

3.3.3.1 Sub-regions

As indicated in section 3.2.5, although most of the questionnaires were completed (i.e., all the questions answered), the resolution used to indicate usual cruising routes, mooring areas, launching sites, and anchorages was not the same among all the respondents (specific locations vs. general areas). For this reason, and to simplify the analysis, the study area was initially divided by the author (with feedback from five people; two with local knowledge of recreational boating) into 16 sub-regions defined by an apparent grouping pattern of all digitised recreational routes (Appendix B.3).

These included two sub-regions representing the western and eastern side of D'Urville Island, and four sub-regions (i.e., West Coast, North Island (2 links), South Island) that although representing areas outside the study area, the survey identified them as potential destinations (Appendix B.3). Since the present study was focused on the potential spread of NIS within the study region and not on the initial NIS introduction, sub-regions outside the study area were not considered in the analysis. Hence, the two regions representing D'Urville Island were grouped into one. Figure 3.4 presents the final 11 sub-regions used in this study.

3.3.3.2 Marine facilities in the sub-regions

The number and type of marine facilities varied considerably among sub-regions (Table 3.10). Anchoring and mooring areas, as well as boat ramps and wharves are present in most sub-regions (80–90%) but in different numbers. In contrast, there are only three marinas in the study region located in sub-regions B, E and G. The latter, where most of the surveyed vessels are berthed, is larger (ca. 500 berthing facilities) and adjacent to Port Nelson, which is recognised as a potential hot-spot for the arrival of NIS (Inglis et al. 2006a,b). This marina is also the first port of call for some international vessels (Floerl et al. 2009). Marinas in sub-regions B and E are relatively small (62 berths and 40 berths, respectively), but frequently used by aquaculture vessels (Piola and Forrest 2009, Stuart et al. 2009).

Sub-region C, which covers the Abel Tasman National Park (a conservation and socio-economic area of national importance (section 1.4), has the highest number of marine facilities (21) and encompasses 36% of the anchoring and 21% of the mooring areas in the study region (Table 3.10). Edge sub-regions A (west) and K (east) also have comparatively high number of marine facilities (19 and 17, respectively), represented mainly by wharves and mooring areas. The number of anchorages (5) in eastern sub-region K, the largest island in the study area, is also comparatively high. As indicated in Table 3.10, all boat ramps and slipways, as well as all marine facilities within sub-regions A–F (except marinas and marine farms), are considered to be tidally exposed (i.e., experience tidal desiccation).

3.3.3.3 Pattern of visits to sub-regions

The number of vessels reported to visit each sub-region varied significantly in both moored ($\chi 2$ = 631.232, DF= 10, $P < 0.005$) and trailered ($\chi 2$ = 278.437, DF= 10, $P < 0.005$) vessels (Fig. 3.5a,b), with sub-regions C, K, G, and I being the most visited (both in summer and in the rest of the year) when trailered and moored vessels were analysed together (Fig.

5.6c). However, there was a statistically significant difference in the spatial pattern of usage of the study region between moored and trailered vessels when the visit information was analysed separately ($\chi2 = 151.05$, DF = 10, $P < 0.005$). Moored vessels appearing to visit sub-regions K, G, and I were considerably higher than the percentage of trailered vessels that visit these regions. Similarly, there was a comparatively larger percentage of trailered vessels that visited sub-region D (Fig. 3.5b). Conversely, there was no significant difference between the summer pattern and the rest of the year in both vessel types ($\chi2$ –moored= 3.356, DF= 10, P= 0.972; Fisher's exact text P –trailered= 0.5491).

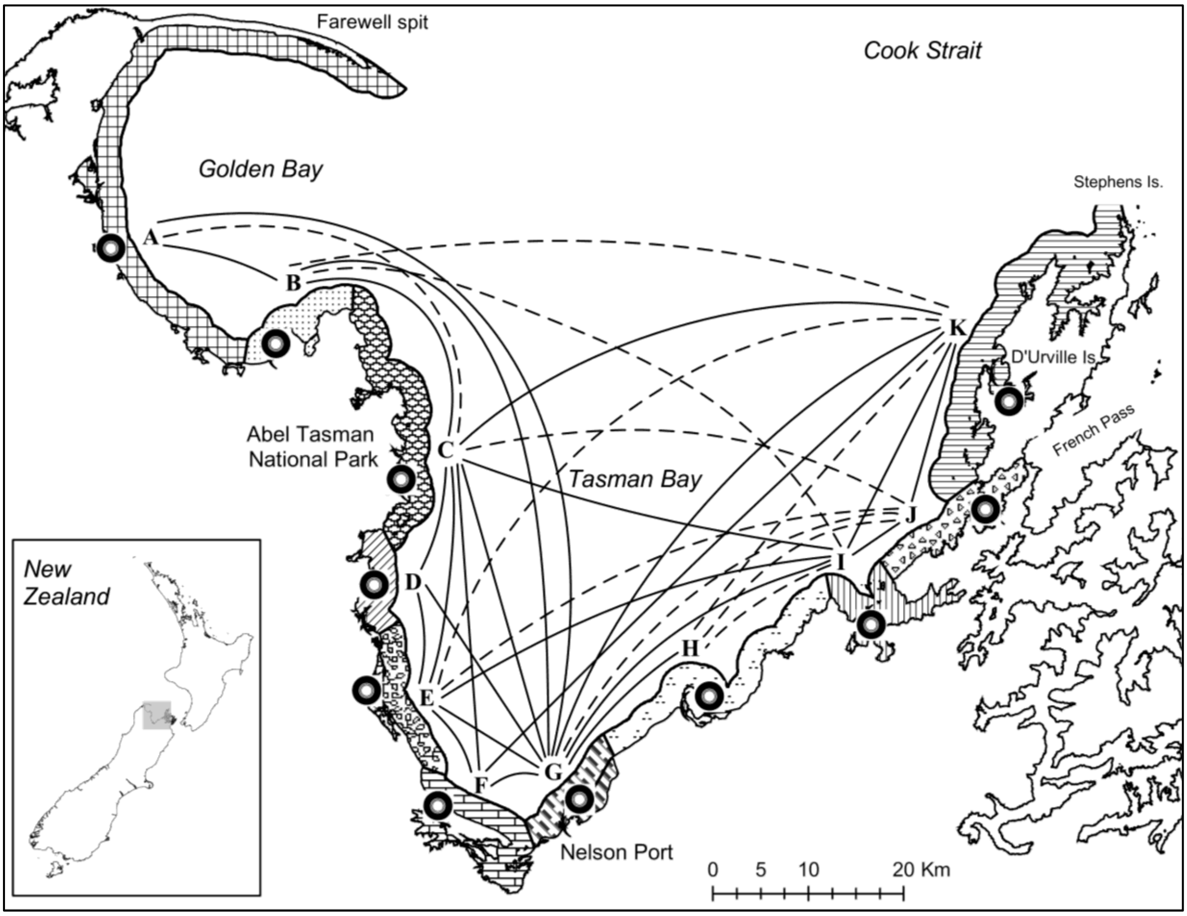

Figure 3.4 Recreational boating in the study region. Golden Bay and Tasman Bay were subdivided into 11 sub-regions labelled A–K and represented in the figure by different patterns along the coastline. Recreational boating generates 33 connections within sub-regions; 23 are used by both moored and trailered (solid lines), and 10 are used only by moored vessels (dashed lines). Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

3.3.3.4 *Connecting routes and Connectivity values (CV)*

The number of connections within sub-regions created by recreational boating in the study area, as well as their usage frequency (i.e., *ac* and CV, respectively, in equation 3.6), depends on the vessel type considered. Moored vessels generated 33 connections between sub-regions, with sub-regions G and C having the highest number of connections (Fig. 3.5, Tables 3.11 and 3.12). Connections $C \leftrightarrow G$ and $G \leftrightarrow I$ showed the highest CV (i.e., 57.6% and

42.4%) in moored vessels. Conversely, trailered vessels only generated 23 connections, and although sub-regions G and C still showed the highest number of connections, only connection *C↔D* had a notably high CV (61.7%) (Fig. 3.5, Tables 3.11 and 3.12). All other connections presented a CV of less than 15%. Although all respondents indicated which areas they would usually visited in summer and during the rest of the year, most of them (>70%) only specified the routes followed in summer. Therefore, no temporal comparison (summer vs. rest of the year) was possible for connecting routes or CV.

Table 3.10 Type and number of marine facilities present in each sub-region. Data from Tasman District Council, Nelson City Council, Marlborough District Council, Murray and von Kohorn (2002), Google Earth imagery and personal observations. Cells highlighted represent facilities assumed to experience tidal exposure. SD= standard deviation.

	Sub-region													
Marine facility	A	B	C	D	E	F	G	H	I	J	K	Total		SD
Anchorage	1	2	10	2	0	0	1	2	3	2	5	28	2.5	2.8
Boat ramps	2	3	2	4	2	2	4	1	2	0	0	22	2.0	1.3
Marinas	0	1	0	0	1	0	1	0	0	0	0	3	0.3	0.5
Marine farms	2	1	0	1	2	0	0	0	5	2	3	16	1.5	1.6
Moorings	6	4	7	3	3	3	2	1	1	0	4	34	3.1	2.1
Slipways	1	1	0	0	1	0	1	0	0	0	0	4	0.4	0.5
Wharves	7	2	2	3	2	4	3	0	2	0	5	30	2.7	2.1
Total	19	14	21	13	11	9	12	4	13	4	17	137	12.5	5.4
$\tilde{x}$	2.7	2	3	1.9	1.6	1.3	1.7	0.6	1.9	0.6	2.4	19.6		
SD	2.7	1.2	4	1.6	1	1.7	1.4	0.8	1.8	1	2.4	12.4		

3.3.3.5 Connectivity ranking value (CR)

As with CV, CR values varied between vessel types and among sub-regions. In all sub-regions (except in sub-regions D and H) CR values for moored vessels were consistently higher ($\tilde{x}$ = 0.48) than values for trailered vessels ($\tilde{x}$ = 0.22) (Table 3.13, Fig. 3.6). Sub-region G (1.80), followed by sub-regions C (1.18), K (0.84) and I (0.67), showed the highest CR when moored vessels were considered. All other sub-regions had comparatively lower CR (< 0.19). In contrast, sub-region C (0.78) had the highest CR when trailered vessels were considered. Sub-regions G (0.54), D (0.24), K (0.24), I (0.19), and E (0.18) also showed comparatively higher CR (Fig. 3.6, Table 3.13). Sub-region A (0.01) had the same CR value in both vessel types, which was also the lowest value among all sub-regions.

3.3.3.6 Priority ranking value

There was a marked, and statistically significant, difference between PRV values of sub-regions, between summer and the rest of the year, and between moored and trailered vessels (Fig. 3.7, Table 3.14). PRV values were consistently higher in moored vessels for both time periods although in summer trailered vessels showed a slightly higher PRV in sub-region D (2.05 > 1.58) (Fig. 3.7). Similarly, all sub-regions showed significantly higher PRV values for summer (Nov.–Mar.) (Fig. 3.7, Table 3.14).

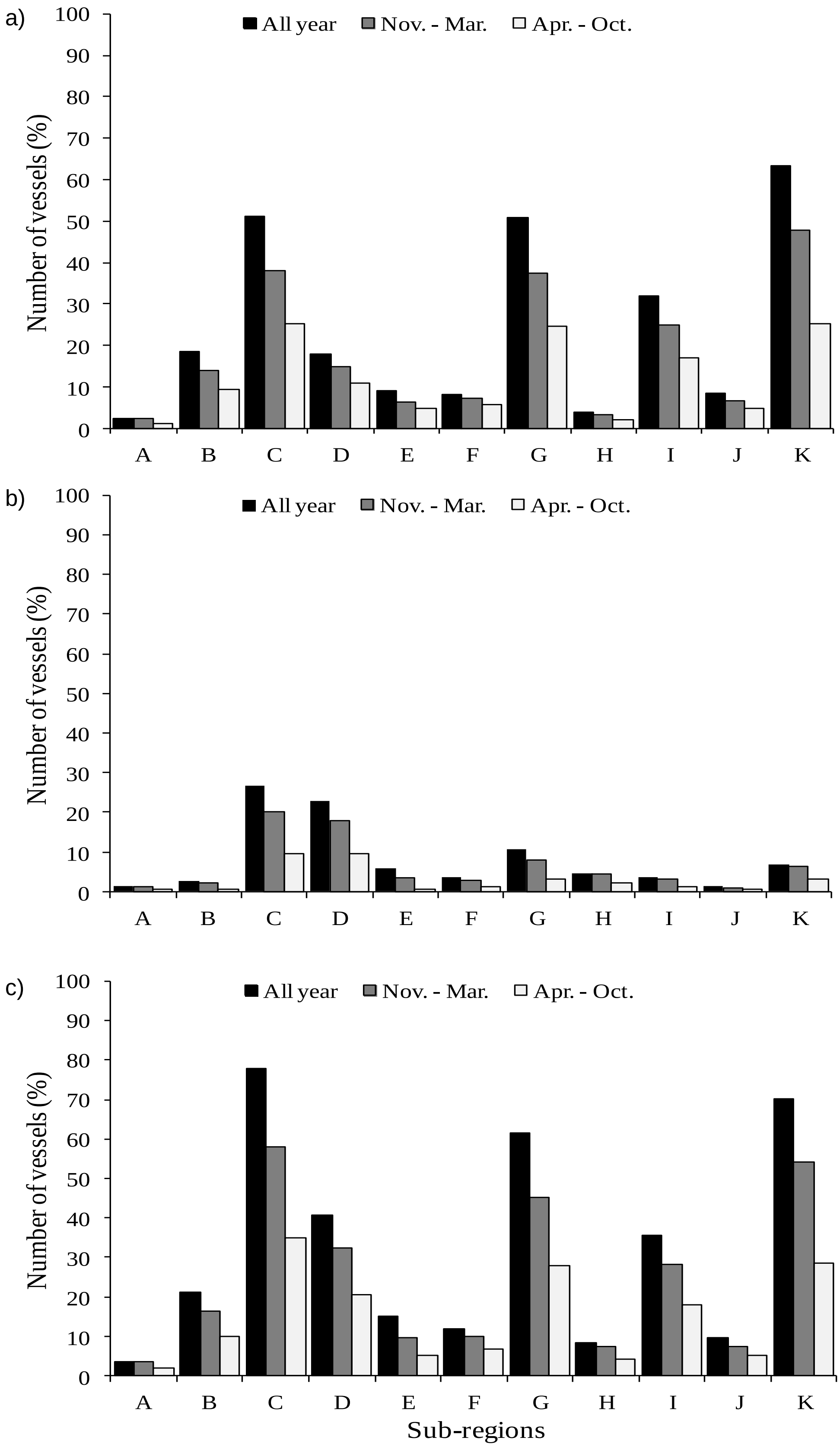

Figure 3.5 Sub-regions visited through the year by recreational vessels in the study region. a) Moored vessels. b) Trailered vessels. c) All vessels. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

Table 3.11 Actual number of direct connections (ac) to other sub-regions created by recreational vessels in the study region. Values used to calculate the Connectivity ranking value (CR) from equation 3.6. The total number of connections under an ideal scenario (pc) was defined as 10 (i.e., maximum number of possible connections). Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

	Recreational vessel			
Sub-region	Moored		Trailered	
	ac	*ac/pc*	*ac*	*ac/pc*
A	3	0.3	2	0.2
B	5	0.5	3	0.3
C	9	0.9	7	0.7
D	3	0.3	3	0.3
E	7	0.7	5	0.5
F	4	0.4	4	0.4
G	10	1	9	0.9
H	4	0.4	1	0.1
I	7	0.7	5	0.5
J	6	0.6	2	0.2
K	8	0.8	5	0.5

Table 3.12 Connectivity value (CV) for connections between sub-regions. CV_{ij} is the percentage of vessels that reported to traveling directly between sub-regions *i* and *j*. Section above matrix diagonal (i.e., dark) represents values for moored vessels. Section below matrix diagonal (i.e., light) represents values for trailered vessels. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

Sub-region *j* / Sub-region *i* (CV_{ij})	A	B	C	D	E	F	G	H	I	J	K
A	A	2	1.5	–	–	–	0.5	–	–	–	–
B	3.5	B	25.4	–	–	–	4.9	–	0.5	–	4.9
C	–	6.1	C	22.9	5.9	1.5	57.6	–	3.9	0.5	11.7
D	–	–	61.7	D	6.8	–	17.6	–	–	–	–
E	–	–	7.8	9.6	E	2	6.3	–	4.4	1	8.3
F	–	–	1.7	–	2.6	F	11.2	–	–	–	1
G	0.9	0.9	7	7.8	3.5	7	G	5.9	42.4	2.4	31.2
H	–	–	–	–	–	–	13	H	2	0.5	0.5
I	–	–	0.9	–	1.7	–	7	–	I	6.8	35.6
J	–	–	–	–	–	–	–	–	2.6	J	11.7
K	–	–	1.7	–	–	1.7	7	–	14.8	4.3	K1

3.3.4 Visits to other regions

A large percentage of moored vessels (71.7%) and trailered vessels (57.4%) indicated visiting areas outside Golden Bay and Tasman Bay, especially in the neighbouring (eastern) region of the Marlborough Sounds; a nationally important marine farming area (Table 3.15). Other regions visited included the North Island (e.g., Bay of Islands, Hauraki Gulf, New Plymouth and Wellington) and the South Island (e.g., West Coast, Christchurch, Fiordland). A small percentage of moored vessels (< 5%) also reported offshore trips to Pacific (i.e., New

Caledonia, Tonga, Vanuatu and Fiji) and the Sub-Antarctic Auckland Island (Table 3.15). Similarly, a small percentage of trailered vessels (7.8%) indicated visiting mainland lakes (Table 3.15).

Table 3.13 Connectivity ranking value (CR). CR calculated using equation 3.6, where CVij is the connectivity value for the connection between sub-regions *i* and *j*, ICVij the ideal connectivity value between these sub-regions (100% in this case), ac the actual number of connections for sub-region i, pc the potential number of connections for sub-region i, and m the total number of sub-regions that could be connected to sub-region i (i.e., 10). = average and SD = standard deviation. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

	Recreational vessels	
	Moored	Trailered
Sub-region *i*	$\left(\sum_{j=1}^{m} {CV_{ij}}/{ICV_{ij}}\right) * {ac}/{pc} = CR_i$	$\left(\sum_{j=1}^{m} {CV_{ij}}/{ICV_{ij}}\right) * {ac}/{pc} = CR_i$
A	0.04 * 0.3 = 0.01	0.044 * 0.3 = 0.01
B	0.377 * 0.5 = 0.19	0.105 * 0.5 = 0.05
C	1.309 * 0.9 = 1.18	0.869 * 0.9 = 0.78
D	0.473 * 0.3 = 0.14	0.791 * 0.3 = 0.24
E	0.347 * 0.7 = 0.24	0.252 * 0.7 = 0.18
F	0.157 * 0.4 = 0.06	0.13 * 0.4 = 0.05
G	1.8 * 1 = 1.80	0.541 * 1 = 0.54
H	0.089 * 0.4 = 0.04	0.13 * 0.4 = 0.05
I	0.956 * 0.7 = 0.67	0.27 * 0.7 = 0.19
J	0.229 * 0.6 = 0.14	0.069 * 0.6 = 0.04
K	1.049 * 0.8 = 0.84	0.295 * 0.8 = 0.24
$\tilde{x}$	0.48	0.22
SD	0.58	0.24

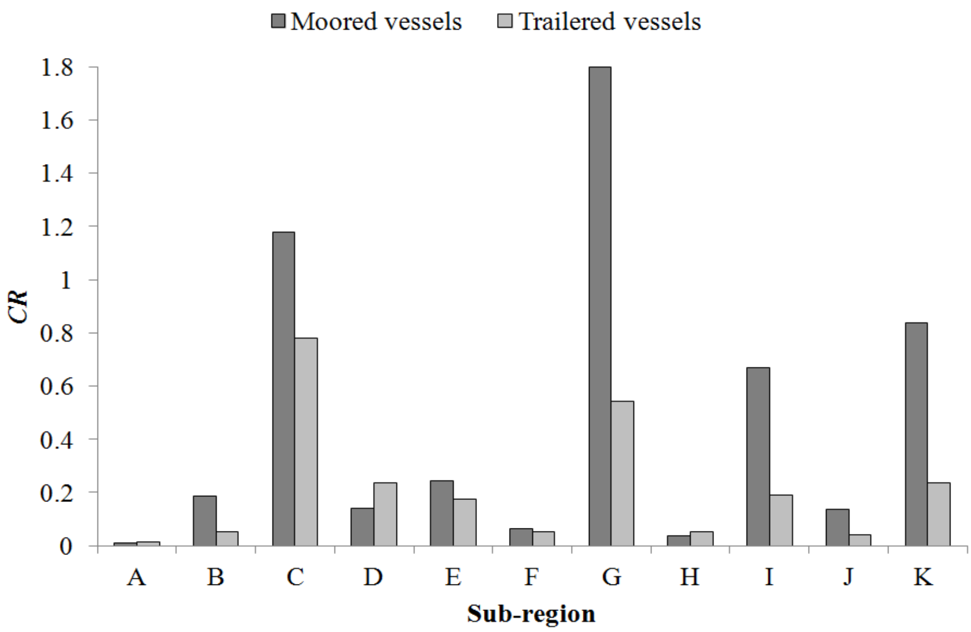

Figure 3.6 Connectivity ranking value (CR). CR is calculated using equation 3.5 that incorporates the number of connecting routes and the frequency of usage of each route, normalising these values by an ideal number of connections and an ideal percentage of usage. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered).

Table 3.14 Results for the Mann-Whitney U Tests and Wilcoxon Matched-Pairs Signed-Ranks Tests. Comparison of visits to sub-regions (11) in the study area by moored vessels and trailered vessels in Nov.–Mar. and Apr.–Oct. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

Mann-Whitney U Test (Moored–Trailered/Nov.–Mar.)

Vessel type	Time period	N	Median
Moored	Nov.– Mar.	11	1.58
Trailered	Nov.–Mar.	11	0.18

Point estimate for Median moored - Median trailered = 1.12

95.1% Confidence Interval for Median moored - Median trailered = (-0.01, 48.93)

W = 155.0

Test of Median moored = Median trailered vs.
Median moored > Median trailered is significant at 0.0330

Mann-Whitney U Test (Moored–Trailered/Apr.–Oct.)

Vessel type	Time period	N	Median
Moored	Apr.–Oct.	11	1.17
Trailered	Apr.–Oct.	11	0.04

Point estimate for Median moored - Median trailered = 0.88

95.1% Confidence Interval for Median moored - Median trailered = (0.01, 28.56)

W = 159.0

Test of Median moored = Median trailered vs.
Median moored > Median trailered is significant at 0.0178 (adjusted for ties)

Wilcoxon Matched-Pairs Signed-Ranks Test

Vessel type	Time period	$\tilde{x} \pm$ sd	W+	W-	N	P
Moored	Nov.–Mar.	20.52 ± 33.58	66	0	11	< 0.05
	Apr.–Oct.	12.95 ± 21.56				
Trailered	Nov.–Mar.	1.81 ± 4.44	63	3	11	< 0.05
	Apr.–Oct.	0.87 ± 2.15				

Table 3.15 Regions visited outside the study region by resident recreational vessels. *Neighbouring region Marlborough Sounds not included in the count for South Island group. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

	Recreational vessels (%)	
Regions visited	Moored	Trailered
Other regions	71.7	57.4
North Island	14.1	20.9
South Island*	5.9	30.4
Marlborough Sounds	69.3	53.9
Sub-Antarctic Islands	1.5	0
Pacific Islands	4.4	0
Lakes	0	7.8

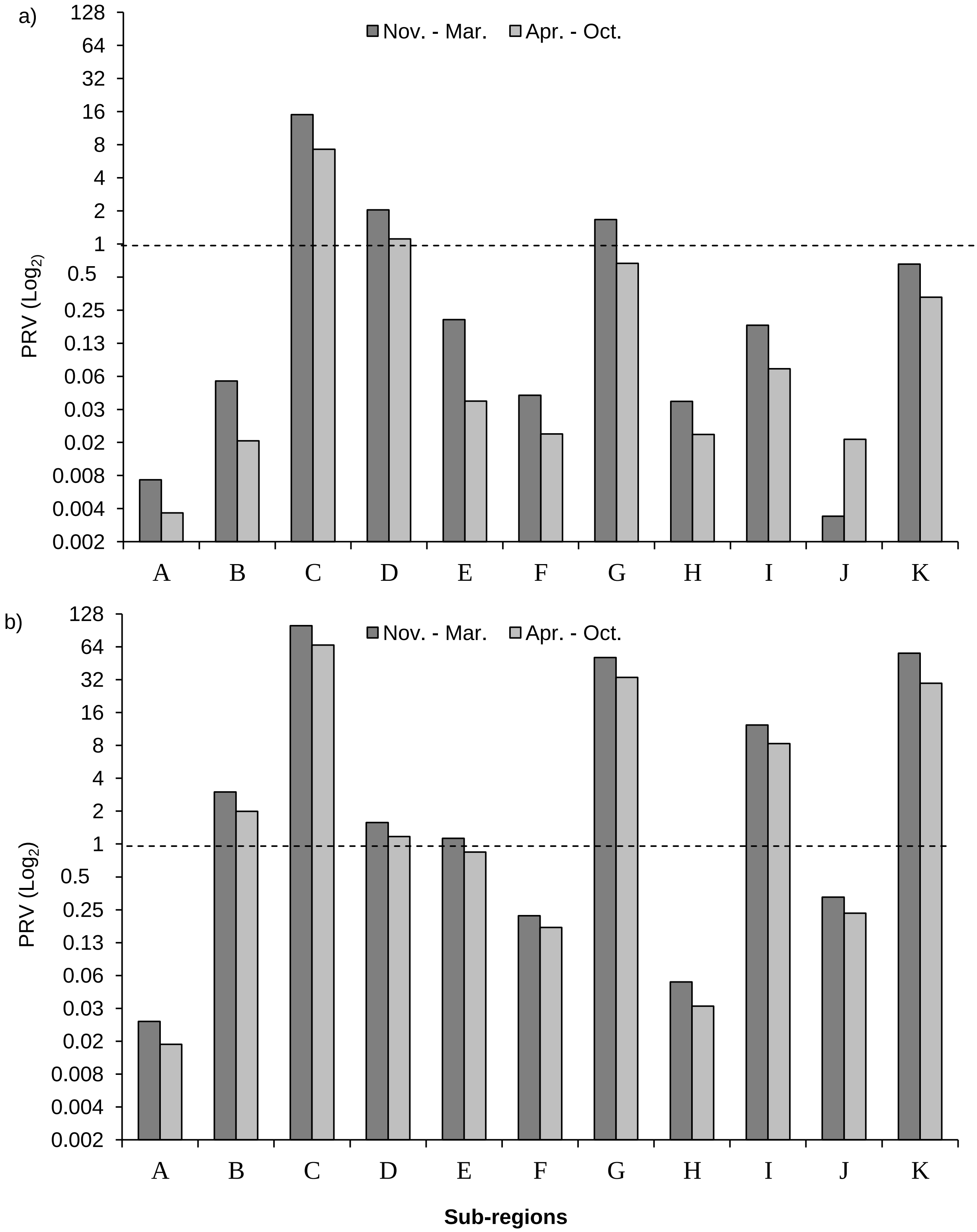

Figure 3.7 Priority ranking value (PRV). PRV calculated based on equation 3.5 that incorporates the Connectivity ranking value (CR) of the sub-region *i* and the sum of the PRV of each marine facility present in this sub-region. a) Trailered vessels, and b) moored vessels. Axis *y* in $\log_2$ scale. PRV = 1 indicated with a dash line to facilitate visual comparison among vessel types. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels = 320 (205 moored and 115 trailered).

3.4 DISCUSSION

3.4.1 Expert opinion and probability of infection in marine facilities

The expert probability of infection, estimated as a result of the probability of release, varied among facilities. Similarly, experts consistently assigned higher probabilities of infection to moored vessels, which implies that experts considered that the vessel–facility interactions that could release NIS into the environment varied between vessel types (Table 3.2, Fig. 3.2). These results are in agreement with other authors (Floerl et al. 2005a, Minchin et al. 2006b, Hayden et al. 2009, Hewitt et al. 2009) who considered the invasion risk to be higher for moored vessels. However, it is possible that experts disregarded the information given in the exercise (i.e., assumed that both vessel types were infected) and using heuristics, such as availability (Tversky and Kahneman 1973), and anchoring and adjustment (Tversky and Kahneman 1974) assigned the requested probabilities. Similarly, it is possible that experts considered the likelihood of visiting the facilities by each vessel type when assigning these probabilities (e.g., moored vessel–marinas, trailered vessels–boat ramps).

As with any expert opinion elicitation process, the baseline information given could have biased the estimates of the participants (Tversky and Kahneman 1981). In this particular exercise, the information provided (e.g., visiting time, activity) was characteristic of the usual interactions between recreational vessels and marine facilities within the study, which ensured that the experts had the same baseline knowledge (Clemen and Winkler 1999, Ayyub 2001).

The highest probability of infection was assigned to the interactions of moored vessels in subtidal marinas. This is in agreement with other literature that considers marinas to be hotspots and beachheads for NIS (e.g., Carlton 1996, Lambert and Lambert 1998, Bax et al. 2003, Arenas et al. 2006, Glasby et al. 2007, Floerl et al. 2009) and thus, it is a priority for surveillance surveys (Hewitt and Martin 2001). Experts also considered the interaction of moored vessels with moorings (especially intertidal) to have a considerably high probability of infection. This is seen in surveillance studies in New Zealand (e.g., Hay 1990, McClary and Stuart 2004, Stuart et al. 2009) and overseas (e.g., Russell and Hewitt 2000, Minchin and Sides 2006) that have detected fouling NIS organisms associated with moorings. It has been suggested that NIS risks associated with moorings in New Zealand may be even higher than in marinas (McClary and Stuart 2004) because: 1) lower costs associated with these facilities relative to marina berths usually result in some moorings being used by poorly maintained vessels, and 2) a relative isolation of some moorings implies low frequency of inspection and maintenance (Piola and Forrest 2009).

As with Acosta et al. (2010), experts engaged in the present study considered the infection probability of anchorages via moored vessels to be comparatively higher than other interactions (Table 3.2, Fig. 3.2). It is important to consider that Acosta et al. (2010) asked their experts to provide not a probability estimate (as in this study), but a risk estimate. This prevents direct comparisons between the studies. Similarly, the risk estimates presented in Acosta et al. (2010) (also based on the probability of detecting NIS if present) were likely to be influenced not only by the heuristics used by each expert (e.g., availability), but also by their perception of risk, which is known to vary among people (Slovic et al. 1979, Johnson and Slovic 1995, Xie et al. 2003). In any case, the high probability (and risk) assigned by experts to anchorages in these two studies contrast with surveillance activities that have found no, or a limited number of, NIS in anchorages (e.g., Meinesz 1999, Aquenal Pty Ltd 2002, Pollard and Rankin 2003, Neil and Stafford 2004).

Slipways and boat ramps were assigned the highest probability of infection for trailered vessels. As indicated by Kinloch et al. (2003) and shown in the present study (Table 3.5), users are likely to clean trailered boats (and sometimes their catch after fishing trips) at these facilities. Therefore, it is possible that some NIS organisms or propagules survive the cleaning process (e.g., ANZECC 1996, Floerl et al. 2005b, Forrest et al. 2007, Woods et al. 2007, Floerl et al. 2010b) and are indivertibly discharged into the environment. In fact, some authors (e.g., Coles et al. 2006) have reported sites near boat ramps having a considerable number of NIS. Experts also ranked the probability of infection of slipways via moored vessels comparatively high. The relatively high probability given by the experts to these facilities is in line with the surveillance priority suggested for baseline port surveys (Hewitt and Martin 2001).

3.4.2 Recreational vessels as vectors for non-indigenous species

Local recreational vessels could also be vectors for both primary and secondary introductions. The survey showed that a large number of vessels, moored (71.7%) and trailered (57.4%), visit places outside the study region (Table 3.15), which is also indicated by previous studies (McClary and Stuart 2004, Floerl et al. 2009). Most of the vessels indicated the neighbouring Marlborough Sound as a main destination, but some also included further destinations in the North Island and South Island, where NIS such as the invasive *Sabella spallanzanii* has been found (Read et al. 2011). As with Floerl et al. (2005), this study showed that there are New Zealand recreational vessels that travel overseas, creating a pathway for international NIS introductions, but the number of such vessels is relatively low (Table 3.15).

Hull fouling has been identified as a vector for at least 16 of the NIS found in the study region (Chapter 1, Table 1.3). Recreational boating could therefore facilitate dispersal of such species within the entire study region. For example, the risk in New Zealand for spreading biofouling bryozoan *Watersipora subtorquata* has been considered non-negligible (Bell et al. 2011). This species, present in the marinas of sub-regions B and G, is known to have a tolerance to antifouling paints that facilitates the transport of other invasive species (Floerl et al. 2004). Similarly, recreational vessels could assist the spread of the ascidian *Ciona intestinalis*, which has been found in sub-region G. This NIS species is considered of ‘medium risk’ in Australia (Hayes et al. 2004a, McDonald 2004) and a pest in some New Zealand and overseas aquaculture regions (Cayer et al. 1999, Caver et al. 2003). In Canada, *C. intestinalis* fouling restricts growth and increases mortality of mussels causing considerable loss of revenue for marine farmers (Daigle and Herbinger 2009).

Hull fouling is not the only mechanism for the spread of NIS via recreational vessels. Internal spaces such as the bilge, seawater intakes and outtakes, and fishing gear have also been identified as potential sub-vectors for NIS (Relini et al. 2000, Hayes 2002a, Klein and Verlaque 2008, Dodgshun et al. 2007, Darbyson et al. 2009). Therefore, it would be possible for these sub-vectors to facilitate secondary introductions of highly invasive species, such as the seastar *Asterias amurensis* should they be introduced into the study region (e.g., Hayes et al. 2004b).

Recreational boating in Golden Bay and Tasman Bay showed a seasonal component of vector activity. Both moored and trailered vessels are more likely to be used between November and March (Fig. 3.3). These are the months identified as most likely for the arrivals of international recreational vessels in New Zealand (Floerl et al. 2005a, Hayden et al. 2009). Patterns of seasonality in the recreational boat activity have also been reported in the country by other authors (e.g., Floerl et al. 2009, Lacoursiére-Roussel et al. 2012), with only one study reporting no apparent seasonality for this vector (i.e., McClary and Stuart 2004). The latter study was limited to moored vessels and the sampling method favoured frequently used vessels, which would have misrepresented the recreational boating activity in New Zealand (McClary and Stuart 2004). The results of the present study also indicated a seasonal pattern for cleaning activities, with moored vessels more likely to be cleaned between October and November (Table 3.9). However, most users of trailered vessels reported cleaning them when they were taken out of the water.

3.4.3 Connectivity ranking value (CR) and Priority ranking value (PRV)

The number of connections created by recreational boating in the study region and their CV varied between vessel types. Moored vessels represented more connections between regions and presented higher CV, especially in *C↔G* and *G↔I*. Similarly, sub-regions G and C showed the highest number of connections (Table 3.11). These sub-regions also had the highest number of connections with trailered vessels, but only connection *C↔D* had a notably high CV (61.7%) (Table 3.12). This could be explained by the fact that sub-region D is the main launching area for trailered vessels visiting the Abel Tasman National Park, located in sub-region C (G. Stricker, pers. comm.).

Sub-region G had a particularly high CR that reflects: 1) its high number of connections (i.e., the maximum possible) and 2) relatively high CV (> 30 %) along some of these connections (Tables 3.12 and 3.13, Fig. 3.6). Such a result was expected as sub-region G includes the main marina in the study region. Higher number of connections with a relatively high CV also generated comparatively higher CRs in sub-regions C, K, and I. Consequently, only these four sub-regions (i.e., G, C, K and I) showed comparatively high PRVs (Fig. 3.7). In this case however, a relatively high CR combined with a larger number of moorings and anchoring areas, and the fact that experts assigned the highest probabilities of infection to these marine facilities (Table 3.2, Fig. 3.12), gave sub-region C (and not G) the highest PRV.

Trailered vessels produce similar CR and PRV patterns, although actual values were consistently lower. Sub-regions G, D, and especially C, were the only ones that showed comparatively high CRs and PRVs. This was consistent with the large number of connections of sub-regions C and G, and high connectivity value (61.7%) between C and D. Although they were consistently higher in summer in both vessel types, the spatial pattern of CV and PRV did not change between time periods.

Prevention strategies that rely on pathway management and surveillance programmes are recognised as the most effective and economic approaches to slowing the escalation of the

NIS problem (Leung et al. 2002, Meyerson and Reaser 2002, Simberloff 2003, Lodge et al. 2006). Spatial prioritisation of surveillance and management based on incursion and spread risk can assist scientists and managers to design improved (i.e., more effective) preventative programmes, as well as to distribute regional biosecurity management resources more efficiently (e.g., Hulme 2009, Herborg et al. 2009, Biodiverse Limited 2010). This prioritisation can also facilitate quick management decisions that are crucial with new NIS incursions, where their potential impact makes their containment and/or eradication a priority (Buckley et al. 2005). Similarly, it can help in the identification of effective control zones; an essential factor in the success of eradication programmes of established pests (Sinner et al. 2009).

Marine invasions via recreational vessels are complex processes that can be affected by a number of species-specific and spatio-temporal variables (Hayes 2002a, Floerl et al. 2005a, Acosta and Forrest 2009, Burgess and Marshall 2011, Lacoursiére-Roussel et al. 2012, Chapter 2). Accordingly, vessel maintenance, traffic volume and connectivity among vessel hubs (Godwin 2003, Piola and Johnston 2008, Floerl et al. 2009), as well as factors such as time spent at the location and habitat type (Minchin and Gollasch 2003), affect the probability of NIS incursions and spread at a specific location via recreational boating. Such factors could therefore be used to estimate risks and prioritise surveillance and management at different locations. However, this should be done through an analytical and integral assessment, such as the one provided by the RPN concept of the FMEA (e.g., Rhee and Ishii 2003, Minchin et al. 2006b, Gust et al. 2008).

Individual assessments of these variables may otherwise, generate biased information and lead to inaccurate spatial risk prioritisations. This is shown in the present study, in using the concept of the RPN to define the PRV, to prioritise management across different areas. For example, when analysing the results for sub-regions A and G, a large number of marine facilities in sub-region A, including moorings that were assigned a high infection probability, initially suggested a high management priority for this sub-region (Table 4.4). However, when this factor was assessed together with the low connectivity of the sub-region using the PRV, sub-region A showed one of the lowest management priorities for both vessel types (Fig. 3.7). Likewise, for moored vessels in sub-region G, the remarkably high connectivity with other sub-regions, and thus high CR, did not imply a similarly high PRV, mainly because of the low number of marine facilities present (Table 3.12, Fig. 3.7).

The PRV, as with any hazard and risk estimate, are affected by uncertainties. In the present study, three important uncertainty sources were recognised. Firstly, the vessel was considered as an integral vector when in reality the risk may vary among vessel components (Hayes 2002a, Hayes et al. 2007, Acosta and Forrest 2009, Chapter 2). For example, there are likely to be differing risks among vessel components such as external fouling, infected deck spaces, infected bilge water, anchors and similar. Secondly, only information from resident vessels was used to calculate PRVs. Of note is that Golden Bay and Tasman Bays are common destinations for recreational vessels from around New Zealand. The scallop (*Pecten novaezelandiae*) season attracts a large number of non-local recreational trailered vessels to the region between July–February. Thirdly, opposite connections were assumed to have the same connectivity (e.g., $CV_{AB}= CV_{BA}$) as the survey respondents did not always differentiate travel direction. In reality, when visiting several locations, vessels tend to do return journeys without following the same path on the return (e.g., *G*→ *D*→ *C*→ *G*), which implies that (between some sub-regions) connections are likely to be stronger in one-direction than the other (e.g., *D*→ *C* > *C*→ *D*). Finally, as it has been recognised that the spatial management unit is an essential (and underestimated) aspect of NIS management (Mehta et al. 2007), the present study used sub-regions as distinct spatial units. Necessarily, the number and boundaries of these sub-regions were, to a large extent, subjectively defined. Hence, different PRVs may be obtained by using different sub-regions (number and limits), by improved resolution of CVs and probability of transfer and release via vessels (i.e., assessing components individually), or by including data from non-resident vessels.

The calculated PRVs are internally consistent and thus, can provide a meaningful comparative measure to prioritise management among sub-regions. Furthermore, the PRV was not conceived to make accurate NIS introduction and dispersion predictions but to identify locations likely to be marine biosecurity management priorities.

As demonstrated in this study, recreational boating creates a complex and wide transport network in Golden Bay and Tasman Bay (Fig. 3.4, Tables 3.12 and 3.13). Such a network could be a potentially effective pathway for the spread of NIS throughout this region, and therefore warrants management. This management should consider that the likelihood of NIS spread varies across coastal areas within the region, making prioritisation desirable.

Reproduction and propagule dispersal of several pests, especially in temperate marine systems, more often occurs in summer months when the activity of recreational vessels in the study region also increases (Fig. 3.2). Over these months, for example, overcrowding in popular anchorages, especially along the Abel Tasman National Park coastline (sub-region C) is common (H. Acosta, pers. obs.). Hence, the probability for NIS entrainment, transport and release by recreational vessels is likely to be the highest during summer. Similarly, the probability of spreading NIS via recreational boating in the region is comparatively higher with moored vessels than with trailered vessels. In addition to their higher risk of infection, especially as the result of biofouling (Floerl et al. 2005a, Minchin et al. 2006b, Hewitt et al. 2009), moored vessels create a more complex NIS spread network (i.e., more and better connections) in the study region. Therefore, compared with trailered vessels, moored vessels are not only more likely to spread NIS within the region, but also are likely to spread NIS more efficiently and over a wider geographic area. For example, CRs and PRVs suggest that if there is an incursion of the aquaculture pest *S. clava* to the eastern sub-region I, which represents a harbour (i.e., Croisilles Harbour) with several marine farming areas, moored vessels are more likely to spread it into other regions than trailered vessels. While trailered vessels could transfer this pest only to four sub-regions, moored vessels could potentially spread it to seven (Table 3.11, Fig. 3.4). The probability of these transfers would also be consistently higher (i.e., higher CVs) along moored vessel connections. Similarly, only moored vessels connect this sub-region with western sub-region B, a relatively distant location that includes important mussel spat catching and farming areas (Section 1.3, Fig. 3.1, Chapter 4).

Despite its low CV, this connection between sub-regions B and I, could have a crucial effect in the spread of the pest across the region, as in many instances, the rate of invasion and success is determined by low probability, distant dispersal events (Edwards et al. 2007). In fact, several of the NIS found in the study region (e.g., *C. intestinalis, U. pinnatifida, Didemnum vexillum*) have been reported in this sub-region (Stuart et al. 2009). Although it is not possible to indentify recreational vessels as the vector of their primary introduction (aquaculture activities could have introduced these NIS), the present study showed that recreational boating could indeed participate in the secondary spread within the study area.

NIS surveillance and management programmes in Golden Bay and Tasman Bay have traditionally targeted sub-region G, specifically its busy port and marina (e.g., Inglis et al. 2006b, Piola et al. 2008). However, the results of the present study showed that with recreational boating, other sub-regions pose equal or higher risks for regional spread of NIS (Figs. 3.4, 3.6 and 3.7). Despite being tidally exposed, which prevent the establishment of subtidal NIS (Stuart et al. 2009), the present study showed the Abel Tasman National Park coastline (sub-region C) as a highly interconnected location with a range of marine facilities frequently visited by recreational vessels, which makes this location a management priority (Table 3.12, Figs. 3.4). Incursions here of intertidal pest could threaten conservation (e.g., marine reserve) and socio-economic (e.g., aquaculture, tourism) values of national importance. A situation such as this has already occurred in New Zealand on the east coast of the upper North Island, with the incursion of the invasive ascidian *Pyura praeputialis* (Jones et al. 2012).

Managing vectors (e.g., McClary and Stuart 2004, Piola and Forrest 2009, Floerl et al. 2010a), as well as periodic NIS surveys (e.g., Hewitt and Martin 2001, Ashton et al. 2006b, Inglis et al. 2006c) in this sub-region (in addition to the inspections of moorings and marine reserve buoys in spring each year for *U. pinnatifida*) is likely to increase the effectiveness and efficiency of biosecurity programmes in Golden Bay and Tasman Bay. It is important to recognise that the study region is not a closed network, but is highly connected with other regions nationally and internationally as a result of recreational vessels and other traffic (e.g., Stuart 2004, Floerl et al. 2009, Hayden et al. 2009), hence both a recipient and donor of NIS. Clearly, the development and implementation of regional-level management initiatives (e.g., Top of the South Marine Partnership) will more likely be effective when undertaken in conjunction with parallel efforts in other regions and at a national level. Similarly, such efforts should assess other considerably important NIS pathways present in Golden Bay and Tasman Bay (e.g., aquaculture, live sea food, and natural currents) and determine the level of interaction with recreational boating.

The relatively small number of experts (i.e., 5) used in the present study should call for caution when interpreting the results. However, it is important to consider that specific measures such as pretesting of questionnaires, providing baseline information, disconfirming information, and the fuzzy logic approach, were implemented to reduce potential bias and improve accuracy of experts' estimates. Similarly, a larger number of experts would not necessarily result in more accurate and reliable data, as dependence among participants highly influences the marginal returns for including additional experts (Clemen and Winkler (1985). This could explain the results of the review of 38 studies that showed that although the largest number of experts used in the studies was 24, 90% of the studies used less than 12 experts and 60% only used 6–8 experts (Walker 2004).

Mathematical approaches for optimising the number of participants in experts elicitation exercises has been limited (Hogarth 1978, Clemen and Winkler 1985, Hora 2004), and to date, there is not an agreed 'ideal/required number' (USEPA 2011, Price et al. 2012). While some authors suggest that the largest possible number of experts should be used, others suggests that this number should be defined based on several aspects such as the objectives of the study, complexity of the model and data to be elicited, and elicitation method used (van Grinsven 2007, USEPA 2011). However, it should be acknowledged that as with most studies (if not all) that have used expert opinion, the number of participants in the present study was ultimately defined by the availability and willingness of experts to participate as well as by time and financial constrains.

Fuzzy logic is now commonly used in fields where uncertainties are present such as modelling and control (Bezdek 1993), signal processing (Castro et al. 2009), computer and communication networks (Fadaei and Salahshoor 2008, Tajbakhsh et al. 2009), diagnostic medicine (Toprak and Güler 2008, Schaefer et al. 2009) and finance (Plikynas et al. 2005, Celikyilmaz et al. 2009). Similarly, fuzzy logic is today frequently used as the preferred method for combining and averaging expert opinion (e.g., Yu and Park 2000, Ferreira Guimarães 2003, Fiordaliso and Kunsch 2005, Chang and Wang 2006, Baraldi et al. 2009, Kaufmann et al. 2009, Damigos and Anyfantis 2011, Page et al. 2012, Sattler et al. 2012, Tatari et al. 2012). However, to date, most studies applying fuzzy logic to expert opinion have used traditional fuzzy sets (i.e., type–1 fuzzy sets, T1FS), and only recently have interval type–2 fuzzy sets (IT2FS) been recognised as a more suitable approach to modelling expert opinion and linguistic uncertainties (e.g., Mendel 2001, Wu and Tan 2006, Wu and Mendel 2007a). As with Acosta et al. 2010, the present study demonstrates the applicability of IT2FS expert opinion in the marine biosecurity field, which to date had not been really explored. This approach is particularly suitable to capture, integrate and represent linguistic uncertainty originated from different understanding of linguistic measurers.

3.5 CONCLUSIONS

Recreational boating within Golden Bay and Tasman Bay appeared as a complex pathway for the introduction and spread of NIS across this region. Expert judgment on the probability of infection and spread varied among vessel types and marine facilities. Moored vessels were assigned higher probabilities among all facilities but especially at subtidal marinas. Slipways and boat ramps were considered to have higher probabilities of infection when assessing trailered vessels as the spread vector. These places were also identified by vessel users as a common place for cleaning both the vessel and the catch. Expert assessments in this study however were likely to be affected by heuristics common to expert–generated data, which could bias the results. By using fuzzy logic, specifically interval type–2 fuzzy logic, biases from different understanding of linguistic measures can be captured, represented, and conserved through the analysis.

The connectivity pattern created by recreational boating among sub-regions was similar between vessel types, but moored vessels showed more and stronger connections. Although the entire region appeared well connected, CV showed sub-regions C and G (which include the main tourist attraction and the main marina in the region, respectively) were better interconnected than the rest of the sub-regions. Similarly, PRV showed these sub-regions, as well as sub-regions D, I and K, likely to be a management priority because of both their connectivity and type of encompassed marine facilities. The CV and PRV concepts presented here appear useful measures that could help to investigate spatial connectivity and thus, help to prioritise research and management activities within and across regions. These measures do not have complicated data requirements and both are internally consistent. Hence, the CV and PRV concepts, modelling approach, and baseline information presented here, could be valuable inputs when designing NIS surveillance activities and assessing response scenarios in the study region. They could also be easily applied in other regions of New Zealand and overseas.

Chapter 4: The New Zealand Greenshell™ mussel (*Perna canaliculus*) aquaculture, a regional pathway for non-indigenous species

4.1 INTRODUCTION

Aquaculture is now well recognised as a means for employment, poverty reduction, and food security[9] (Ahmed and Lorica 2002, Msuya 2006, Troell et al. 2006, Kaliba et al. 2007, Robertson-Andersson et al. 2008, FAO 2010). In particular, marine aquaculture is considered a way to improve food security of countries and households, and provide nutritional and health benefits while reducing poverty (Engle 2010).

Marine aquaculture, which has undergone rapid growth on coasts worldwide (FAO 2009), is a diverse industry that could help to meet the nutritional needs of a growing population, expand economic opportunities in coastal communities and produce seed stock to restore depleted populations (Marine Aquaculture Task Force 2007). This industry has also been suggested as an alternative source of seafood to the declining harvests from wild fisheries (Costa-Pierce 2002), and as such, aquaculture is now one of the most important and fastest growing sectors within the fishery industry (Burrel and Meehan 2006, Hewitt and Campbell 2007). Marine aquaculture however, has also been implicated in ecological impacts and large-scale environmental changes such as eutrophication (Carroll et al. 2003, Dowd 2005), marine debris production (Hinojosa and Tiel 2009), and habitat and biodiversity loss (Choo 2001, Kaiser 2001). There is also increasing evidence implicating marine aquaculture in the introduction, incubation and further spread of non-indigenous species (NIS) (e.g., Beveridge et al. 1994, Fuentes et al. 1995, Ribera and Boudouresque 1995, Inglis et al. 2000, Wasson et al. 2001, Minchin and Gollasch 2002, Wolff and Reise 2002, Mineur et al. 2007, Darbyson et al. 2009,). In particular, shellfish farms are considered potential havens for NIS (Rocha et al. 2009).

NIS are today considered one of the main causes of environmental changes related to human activities in the ocean (Vitousek et al. 1997, Sala et al. 2000) and one of the main threats to marine biodiversity and ecosystem function (Norse 1993, Vitousek et al. 1997, Carlton 2000, Bax et al. 2003). Some of these changes can generate major economic and social impacts (Pimentel et al. 2000, Colautti et al. 2006), especially when they affect aquaculture industries (see section 1.1.3). In Canada, for example, the invasion of the seaweed *Codium*

[9] 'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life' (FAO 2011).

fragile has caused an economic loss of over US$ 1.2 million per year to the aquaculture industry (Colautti et al. 2006). Similarly, in Shakespeare Bay, New Zealand, it was estimated that over five years the presence of *Didemnum vexillum* could cause an income loss of NZ$ 0.8 million to the aquaculture industry (Sinner and Coutts 2003). Ironically, in both cases the aquaculture industry affected, has itself been responsible for the spread of NIS throughout farming areas in the past. Management of NIS, based on sound risk assessment, is therefore a priority for any marine aquaculture industry; particularly when NIS become invasive (Dumbauld et al. 2009).

In New Zealand, marine aquaculture is a multimillion dollar industry (PricewaterhouseCoopers Limited 2006), in which the main species are the New Zealand Greenshell™ mussel[10] (NZGM) *Perna canaliculus*, the Pacific oyster *Crassostrea gigas* and the king salmon *Oncorrhynchus tshawytscha* (Ministry of Fisheries 2008*).* Aquaculture exports in 2009 were approximately NZ$ 280 million, with NZGM representing 83% (33,816 tons) of the volume and 72% (NZ$ 202.5 million) of the value of such exports (Aquaculture New Zealand 2011). The expansion of NZGM aquaculture during the last few decades has made it the principal seafood industry in New Zealand (Burrel and Meehan 2006) and one of New Zealand's iconic exports. As a result, most of the coastal aquaculture areas within the country are related to this industry (MFA 2005, Aquaculture New Zealand 2012).

New Zealand aquaculture, as with most aquaculture industries around the world, has also been associated with ecological impacts and environmental degradation (e.g., Gillespie 1989, Cole 2002, Grange 2002, Markowitz et al. 2004). Although such impacts have not been characterised (let alone quantified), they are likely to increase following the sales target of NZ $1 billion per annum by 2025 that was set by the industry in 2006 (Burrell and Meehan 2006). Therefore, strategies that minimise the impact of aquaculture and promote environmental sustainability are essential, and should include managing the industry as a NIS pathway. Such strategies need to be based on risk assessments that allow managers to define preventive measures and avoid crises. Risk management, the ultimate goal of risk assessment, is unlikely to be effective in the absence of sound conceptual models that clearly reveal the complexity of the analysed systems (Smallman 1996).

The general objective of this study was to provide information that could potentially be used to define and implement effective biosecurity management strategies for the aquaculture industry in Golden Bay and Tasman Bay. The specific objectives of the study were: 1) to develop a comprehensive conceptual model of marine aquaculture as a potential pathway for NIS in this region, 2) to collect and generate baseline information on the movement and cleaning of aquaculture components, as well as on their ability to retain fouling and water/sediment, and 3) to identify potential interactions of aquaculture with other pathways. The NZGM industry was used as a case study, as this is the main aquaculture practice not only in this region but also in New Zealand. Also, the NZGM growing process comprises a range of components and processes, some also representative of other aquaculture industries (e.g.,

[10] The name Greenshell™ is a certified trademark but the correct common name is Green-lipped mussel.

Pacific oysters). The model characterised the components and processes of the NZGM aquaculture in the study area.

4.2 METHODOLOGY

Although there was some information (e.g., location of marine farms) already available from regional government and non-government agencies, most of these data were collected and generated via two surveys among stakeholders of the NZGM industry of Golden Bay and Tasman Bay. Both surveys were approved by the Auckland University of Technology Ethical Committee (Reference AUTEC 10-224).

A total of 20 people were invited to participate in the first survey. This included people from nine large mussel growing companies, five independent mussel growing farmers, and five scientists from research companies with experience in the NZGM aquaculture in Golden Bay and Tasman Bay. Companies were considered to be large if they either 1) own and/or manage marine farms not only in Golden Bay and Tasman Bay but also in other regions, 2) own specialised aquaculture vessels that operate in at least Golden Bay, Tasman Bay and the Marlborough Sounds, or 3) own mussel processing plants. Companies and people were identified as potential participants because either the author knew them, or their name was associated with the NZGM aquaculture industry in publicly available resources (e.g., yellow pages, internet websites). All people who participated in the first survey were invited to participate in the second survey. Surveys were conducted between October 2010 and July 2011.

The first survey was in the form of a structured questionnaire filled out during personal interviews. Any relevant information provided during the interviews was also recorded. All the interviews were conducted by the author using the conversational interviewing technique (Suchman and Jordan 1990, 1991). An initial questionnaire was pretested (Rea and Parker 1997) with four people: two people with knowledge of the aquaculture industry in New Zealand and two lay people. The questionnaire was improved with their feedback and suggestions. These people were not included in the surveys.

The first survey with marine farmers focused on four main aspects of the NZGM industry in Golden Bay and Tasman Bay: 1) the identification of the components and their location, 2) the exchange of gear and product (i.e., spat and growing mussels) between marine farms, 3) gear and product cleaning practices, and 4) the likelihood of NZGM aquaculture components retaining water/sediment or fouling when transported (Appendix C.1). Questions were restricted to objective, direct, short and closed-ended questions, and where possible, a multiple choice format was used (Weisberg et al. 1996, Salant and Dillman 1994). The first question however, asked participants to analyse a model and make any changes they considered necessary to have a comprehensive and accurate conceptual model for the NZGM growing process in Golden Bay and Tasman Bay. The first survey with scientists was similar but shorter as it did not include questions only relevant to marine farmers (e.g., ‘what do you do with the spat catching gear when the season is over?’) (Appendix C.2).

Following a Delphi approach (Dalkey and Helmer 1963, Helmer 1967a,b), the initial conceptual model was modified with feedback from the first survey and emailed to all participants as part of a second survey (Appendix C.3). The second survey also included a model representing the actual location of the marine farms and other components (e.g., processing plants, hatcheries) of the NZGM industry within the study region. Participants were again asked to analyse these models and suggest any changes they considered necessary to have a truthful conceptual model for the NZGM growing process in Golden Bay and Tasman Bay. The second survey was the same for marine farmers and scientists. New feedback and suggestions were used to update the models.

4.2.1 Likelihood estimates, averaging and statistical analysis

Previous conversations the author had had with stakeholders made evident that the answers to several questions regarding some of the aquaculture practices in the region such as cleaning gear between farms would not be discrete (i.e., yes/no) as they might be influenced by a range of factors (e.g., type of gear, 'dirtiness'). Probability terms were therefore considered more appropriate for answering such questions. The questionnaire of the first exercise followed the same methodology presented in Chapter 3 (section 3.27) and Appendix B.2, and all questions where answers implied a probability estimate required the participants to answer choosing either: 1) Very unlikely, 2) Unlikely, 3) Likely, or 4) Very likely. The final section of the first survey also included an exercise to assess the 'natural scale' each respondent associated with these words, and thus, allowed the use of fuzzy logic (Zadeh 1965), in particular interval type–2 fuzzy logic (IT2FL, Mendel 2001) to combine and analyse their answers. Expert likelihood estimates (i.e., words) were combined using the Linguistic weighted average (LWA, Wu and Mendel 2007), following the procedure described in Chapter 3 (section 3.27) and Appendix B.2. All fuzzy logic analyses were conducted using the Open–source software QtOctave (www.ohloh.net/p/qtoctave).

In addition to assess the variability of the interval–type 2 fuzzy sets via uncertainty (Wu and Mendel 2007), non–parametric statistics were used to determine if the differences between the answers of marine farmers and scientists were statistically significant. Due to the small size of the dataset (i.e., 14 people), and thus the presence of small expected numbers in the analyses, it was necessary to apply the randomisation test of independence (McDonald 2009). Similarly, in order to increase the power of the test, answers 'I do not know' and 'No answer' were pooled together as 'Null set', answers Very unlikely and Unlikely as 'Unlikely set', and answers Likely and Very likely as 'Likely set'. The number of replicates used in each analysis when applying the randomisation test of independence was 10000[11]. All statistical analyses were conducted using the Open–source software R version 2.13 (R Development Core Team 2008).

[11]The randomization is based on Fisher's exact test and works by generating random combinations of numbers in the R×C table of such a test, with the probability of generating a particular combination equal to its probability under the null hypothesis. For each combination, the Pearson's chi-square statistic is calculated. The proportion of these random combinations that have a chi-square statistic equal to or greater than the observed data is the P-value (McDonald 2009).

4.2.2 Identification and risk-ranking of aquaculture sub-vectors

As with shipping (GISP 2008, National Research Council 2008, Hewitt et al. 2009), the aquaculture vector can be divided into sub-vectors based on the characteristics and interactions of its components. Initially, the present study defined three aquaculture sub-vectors: 1) vessels, 2) gear, and 3) product (i.e., spat and growing mussels). These sub-vectors are further comprised of different components, where the potential to entrain and transport NIS could vary considerably, hence each of these components were in turn considered as distinct sub-vectors (Table 4.1). The present study acknowledged the vessel and its components (e.g., hull, internal spaces, anchor) as potential sub-vectors, as well as their essential role in the transport of gear and product within pathway components (aquaculture network) such as marine farms and processing plants. However, vessels were not specifically analysed from a risk perspective; mainly for simplicity, but also because these components are not directly related to spat catching and growing processes. The overall risk of a vector spreading a NIS ('the hazard') would depend on the likelihood of the vector translocating this NIS between regions and the consequences (e.g., environmental and economic impacts) this could have.

The likelihood of a vector translocating a NIS would depend on the characteristics of the vector (sub-vector) itself, the NIS considered, and whether or not there are any vector management measures in place that could reduce such likelihood. For example, while ballast water has been identified as the main sub-vector for species such as the Northern Pacific seastar *Asterias amurensis* (Dommisse and Hough 2004, Global Invasive Species Database 2005), hull fouling is considered the main sub-vector for *Styela clava* (Davis and Davis 2004, 2005, 2006) and *Watersipora subtorquata* (Allen, 1953, Floerl et al. 2004, Ferreira et al. 2006). Similarly, the implementation of NIS mid-ocean ballast exchange water (e.g., MAFBNZ 2005) and good hull husbandry practices (e.g., frequent cleaning and reapplying of antifouling paint (Floerl et al. 2005a, Piola et al. 2009), respectively, would affect (reduce) the likelihood of translocating NIS via these vectors.

Table 4.1 Potential sub-vectors identified for the NZGM industry in Golden Bay and Tasman Bay. *Only present in specialised aquaculture vessels**.**

Aquaculture component	Potential sub-vectors
Vessel	Hull (including propeller and rudder)
	Deck
	Internal spaces
	Anchor
	*Declumping equipment/machine
	*Seeding equipment/machine
Aquaculture gear	Backbone rope
	Spat rope
	Culture rope
	Buoys
	Anchors
	Bags
Product	Spat
	Growing mussels

The present study assumed that the risk of an aquaculture sub-vector spreading NIS between farming regions was highly dependent on NIS considered, as well as on the likelihood of the sub-vector entraining, transporting, and releasing NIS between marine farms. The likelihood of transporting the NIS would be in turn, highly dependent on the cleaning conducted on the sub-vector between marine farms. Hence, the risk of spreading NIS between farming regions of each of the aquaculture sub-vectors considered was ranked based on the combination of their estimated (via the survey) likelihoods of: 1) retaining fouling or water/sediment (Hayes 2002a, Chapter 2) when moved between marine farms, 2) being moved between marine farms, and 3) being cleaned when moved between marine farms. This was done based on a risk-rank lookup table previously defined by the author (Table 4.2). When the likelihoods of retaining water/sediment and retaining fouling differed for the same sub-vector, the precautionary principle[12] was applied and the highest likelihood between them was used to define the risk of the sub-vector.

Table 4.2 Risk rank lookup table. Risk rank assigned by the author based on the combination of the likelihoods of 1) retention of fouling or water/sediment by the vector when moved, 2) movement of the vector, and 3) cleaning of the vector when moved. The assumptions used when creating this table are indicated in the text.

Likelihood of			Risk rank
Retention	Movement	Cleaning	
Vl	Vl	Vl	Medium
Vl	Vl	L	**High**
Vl	Vl	U	**High**
Vl	Vl	Vu	**High**
Vl	L	Vl	Low
Vl	L	L	Medium
Vl	L	U	**High**
Vl	L	Vu	**High**
Vl	U	Vl	Low
Vl	U	L	Low
Vl	U	U	Medium
Vl	U	Vu	Medium
Vl	Vu	Vl, L, U, Vu	Low
L	Vl	Vl	Low
L	Vl	L	Medium
L	Vl	U	**High**
L	Vl	Vu	**High**
L	L	Vl	Low
L	L	L	Low
L	L	U	**High**
L	L	Vu	**High**
L	U	Vl	Low
L	U	L	Low

[12] The precautionary principle here is used following Raffensperger and Tickner (1999): 'when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.'

Likelihood of			Risk rank
Retention	Movement	Cleaning	
L	U	U	Low
L	U	Vu	Medium
L	Vu	Vl, L, U, Vu	Low
U	Vl	Vl	Low
U	Vl	L	Low
U	Vl	U	Medium
U	Vl	Vu	Medium
U	L	Vl	Low
U	L	L	Low
U	L	U	Low
U	L	Vu	Medium
U	U	Vl	Low
U	U	L	Low
U	U	U	Low
U	U	Vu	Medium
U	Vu	Vl, L, U, Vu	Low
Vu	Vl, L, U, Vu	Vl, L, U, Vu	Low

The author created the risk-rank lookup table indicating his perceived risk (i.e., Low, Medium, or High) of any aquaculture vector spreading NIS (the hazard) between marine farms for each possible combination of likelihoods (i.e., Very unlikely, Unlikely, Likely, Very likely) of: 1) retaining fouling or water/sediment when moved between marine farms, 2) being moved between marine farms, and 3) being cleaned when moved between marine farms (Table 4.2). For this, the author made the following assumptions:

- The introduction and spread of any NIS (even those not considered 'unwanted organism' in New Zealand) would have the same non-negligible impact on the economic, environmental, social and/or Māori values of the receiving farming region,
- If translocated between farming regions via spat, mussels or gear, any NIS could be released into and survive in the receiving environment/marine farm,
- All sub-vectors had direct (e.g., ropes) or indirect contact (e.g., bags) with the environment for a period of time long enough to allow the entrainment(source)/release(destination) of viable organisms (and/or propagules) of NIS, and
- If either 1) the likelihood of retention was Very unlikely, or 2) the likelihood of movement was Very unlikely, the risk was Low regardless of the values of the other likelihoods.

4.3 RESULTS

A total of 14 (out of 19) people agreed to participate in the first survey: eight operational managers (representing eight mussel growing companies) and six scientists (representing three research companies) (Table 4.3). None of the invited independent marine farmers participated in the study. Nonetheless, the eight participating companies represent about 90% of the NZGM industry of Golden Bay and Tasman Bay (M. Mandino, pers. comm.). Only seven people (four marine farmer and three scientists) completed the second survey. All the participants of the study indicated they had several years of experience in the aquaculture industry. The operational managers had between 8 and 35 years of experience, and the scientists had between 11 and 15 years of experience (Table 4.3).

4.3.1 Conceptual Model

The final conceptual model conceived the NZGM aquaculture as a system (or network) with the following 10 main components, or nodes, distributed through the study region: 1) spat catching sites, 2) holding sites, 3) growing sites, 4) wharves, 5) processing plants, 6) gear cleaning facilities, 7) research facilities, 8) hatcheries, 9) spat cleaning facilities, and 10) land storages (Figs. 4.1 and 4.2). Wharves are not directly related to aquaculture activities, yet they were considered part of the system because of their essential role as nodes within the network. Although it is common to refer to any of the first three components simply as marine farms, the present model made a clear distinction between them to indicate that each component plays a different role in the aquaculture process.

Spat catching sites are areas where naturally-occurring spat is collected. Spat used in all the farms of the study region is either: 1) locally collected (local spat), 2) collected from northern New Zealand (usually referred as ‘Kaitaia spat’), or 3) collected in the Marlborough Sounds (Figs. 4.1 and 4.2). Spat from local hatcheries (there are currently two hatcheries in the study region) are also used in the farms, although in a significantly lower percentage (<10%; D. Herbert, pers. comm.). Local spat catching occurs at five different sites: two in Golden Bay and three in Tasman Bay (Fig. 4.1). For this, long lines with weighted spat ropes (i.e., fibrous or plastic mesh ropes where spat can settle) are suspended in the water using an aquaculture system with backbone ropes, flotation buoys and anchors (see Jeffs et al. 1999). After 4–8 weeks when a considerable amount of drifting spat settles on the ropes, they are retrieved from the water and the spat seeded onto growing or culture ropes. The culture ropes are covered with the spat and wrapped with cotton stocking, which is usually done on board servicing vessels. Seeded culture ropes are then transported (usually in plastic bags on the deck) to holding and growing areas (Table 4.4, Fig. 4.2). Spat collected in the Marlborough Sounds undergoes a similar process when transported to and seeded in Golden Bay or Tasman Bay.

Spat catching in Golden Bay and Tasman Bay is seasonal. In Tasman Bay spat catching structures are removed when the season is over and taken to land storage facilities (although this varies, structures are usually in the water between November and April), whereas in Golden Bay they are permanently in the water and used for mussel growing (Table 4.5).

Although most of the local spat is used to seed only local marine farms, depending on factors such as amount collected, availability of spat from other regions, as well as local and national demand, this spat may be transported (by sea and land) to farms outside the region (i.e., Coromandel Peninsula, Marlborough Sounds and Banks Peninsula) (Table 4.6).

Table 4.3 Participants of the surveys.

Respondents		Company	Experience (number of years in the aquaculture industry)	Surveys completed
Marine farmers	1	A	13	1,2
	2	B	8	1,2
	3	C	No answer	1
	4	D	No answer	1
	5	E	35	1,2
	6	F	30	1
	7	G	13	1,2
	8	H	No answer	1
Scientists	1	I	11	1,2
	2	I	15	1,2
	3	I	12	1
	4	I	15	1
	5	J	17	1,2
	6	K	15	1

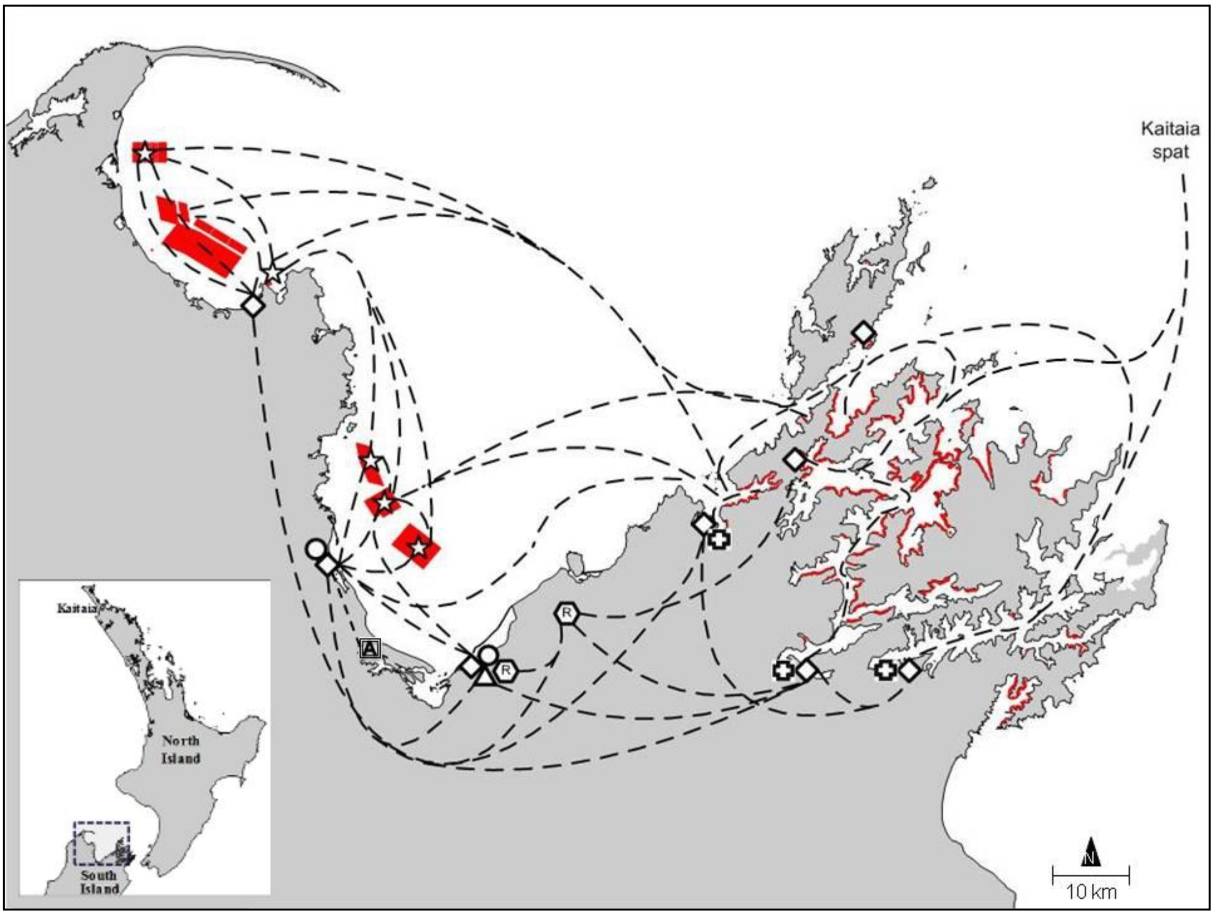

Figure 4.1 The NZGM industry as a potential pathway for NIS in Golden Bay and Tasman Bay, New Zealand. This figure shows the movements of vectors between aquaculture nodes within the study region (◇wharves, ✣ spat cleaning facilities, △hatcheries, ○ processing plants, ☆spat collecting sites, ■ growing/holding sites, Ⓡ research facilities, 🄰 public aquaria).

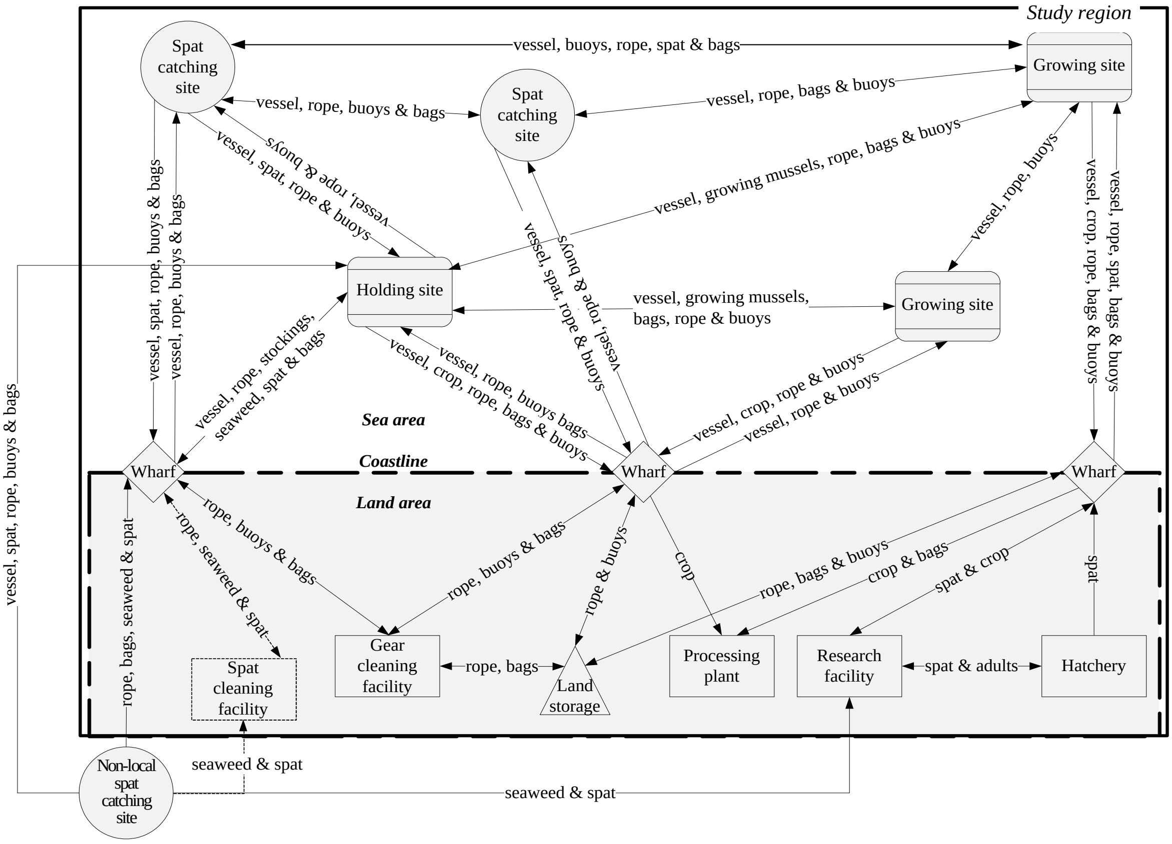

Figure 4.2 Aquaculture conceptual model. Main New Zealand Greenshell Mussel aquaculture components and movements of potential vectors for NIS in Golden Bay and Tasman Bay.

Table 4.4 Transport of spat between marine farms. Answers of eight operational managers of New Zealand Greenshell mussel farms in Golden Bay and/or Tasman Bay to the question 'If the spat is used in other farms, how it is transported there?'

Transport of spat	Number of respondents
Ropes laid on deck	2
Ropes stripped and reseeded	7
Ropes put in bags on deck	8

Table 4.5 Aquaculture gear when not in use. Answers of eight operational managers of New Zealand Greenshell mussel farms in Golden Bay and/or Tasman Bay to the question 'What do you do with the following gear when not using it in your farm for the spat catching (growing) process?' *Only anchors from seasonal spat catching gear are removed from the water.

Aquaculture component	Leave it in the water	Use it in the spat catching/growing process	Use it in other farms	Store it on land
Backbone rope	4			6
Spat rope			2	6
Culture rope			4	6
Anchors*	7			6
Buoys	3	5	6	7
Bags		4	2	3

Kaitaia spat catching is a completely different process. Spat from large offshore beds settles on drifting seaweed that later is found on the beach (Jeffs et al. 1999). Both seaweed and spat are collected in bags and transported to different aquaculture regions throughout the country (Fig. 4.1). Both algae and spat are wrapped around the ropes with cotton stocking. Seeded ropes are then suspended in the water from long lines attached to the backbone ropes of holding and growing farms. This process is usually done from specialised aquaculture vessels. In the water, algae and stocking disintegrate, while the spat attaches to the rope and continues its development.

A bloom of the planktonic microalga *Gymnodinium catenatum,* responsible for paralytic shellfish poisoning in humans (Ochoa et al. 1998) and responsible for the closure of shellfish aquaculture areas around the world (Rhodes et al. 2001), was detected in the Kaitaia region in May 2000 (MacKenzie and Beauchamp 2000). This led the NZGM industry to implement a voluntary treatment for Kaitaia spat to prevent the spread of *G. catenatum* (Taylor 2000). Before the Kaitaia spat could be used in Golden Bay and Tasman Bay farms, samples had to be analysed at research facilities to determine whether it was contaminated with cysts of this dinoflagellate. If cysts were detected, seaweed and spat had to be thoroughly cleaned in one of the three facilities specially built in the study region for this purpose (Fig. 4.1). Once it was determined that the spat was clear of *G. catenatum* (absent or treated at the facilities) culture ropes could be seeded. These measures are not currently in place as no blooms have been detected for several years, but they could be readily implemented if required (i.e., if a bloom of *G. catenatum* is detected in the Kaitaia region again).

Table 4.6 Golden Bay and Tasman Bay spat use. Answers from eight marine farming operational managers of Golden Bay and/or Tasman Bay to the question 'Where is the spat collected in your farm used?'

Spat destination	Number of respondents
Golden Bay	8
Tasman Bay	8
Marlborough Sounds	8
Coromandel Peninsula	2
Banks Peninsula	1

Holding and growing sites are farms where mussels are kept while growing (Fig. 4.2). There are four general holding and growing areas in the study region: 1) Golden Bay, 2) Croisilles Harbour, 3) French Pass and 4) D'Urville Island (Figs. 1.2 and 4.1). Holding sites are the initial locations where spat and small mussels are kept temporarily until they reach a reasonable size, so they can be manipulated more easily without damaging or dislodging them from the ropes. Mussels are moved to growing farms, directly or after being reseeded onto other ropes and left there until they reach a marketable length (90–120 mm). During the reseeding process, sediment and biofouling, which might include the NIS blue mussel *Mytilus galloprovincialis* and invasive pest *C. intestinalis,* are cleaned off the product and discarded directly back into the sea (Barnaby 2004, Table 4.7). This process is conducted from a specialised vessel equipped with a mechanical de-clumping that detaches mussels from the ropes. The point of discharge, which includes the water used to clean the mussels (referred as 'washwater'), varies depending on the position of the vessel, but it is always within a consent area (Aquaculture New Zealand 2007). It is not uncommon to use a farm for both holding and growing, or to move juveniles within and between holding and growing farms (M. Holland, pers. comm.).

When mussels reach marketable size, they are retrieved from the water, detached from the ropes and once again cleaned of any biofouling (also discharged into the environment). Cleaned mussels, commonly referred at this stage as crop, are placed in large bags (sacks), and landed, to be transported by truck to processing factories for further cleaning and packaging. Depending on the company, and thus the processing factory used, the crop can be landed at Golden Bay (Port Tarakohe), Tasman Bay (Port Nelson or Okiwi Bay) or the Marlborough Sounds (Elaine Bay, Havelock, Port Marlborough or Port Underwood) (Figs. 1.2 and 4.1). Even though there is no clear boundary between these pathways, the model assumed that once the mussels reach the processing plant, they leave the aquaculture pathway and enter the live seafood pathway.

It is important to note that although wharves are not part of the actual spat catching and growing process, most of the time they are an essential link between many of the components. Therefore, wharves were considered a component in the model (Figs. 4.1 and 4.2). Similarly, although not analysed, gear cleaning facilities and land storage facilities were considered a component in the model because when it is not in use, some aquaculture gear might be cleaned (e.g., ropes, sacks) or stored (e.g., ropes, buoys) in these facilities (Fig. 4.2).

Table 4.7 Cleaning residues discharge. Answers of six scientists and eight marine farming operational managers of Golden Bay and/or Tasman Bay when asked 'Where are the cleaning residues discharged?' NA: Not applicable, IDK: I do not know.

	Marine farmers				Scientists			
Aquaculture component	NA	IDK	Over-board	On land	NA	IDK	Over-board	On land
Spat	2		6			1	5	
Growing	2		6			1	5	
Spat rope	2		6			1	5	2
Culture	2		6			1	5	2
Backbone	-	-	-	-	-	-	-	-
Buoys	1		7			2		
Anchors	6		1	1	1	1	3	
Declumping equipment	1		7				5	
Seeding equipment	1		7				5	
Bags	1		6	1		2	3	2
SCUBA– diving gear	4	1	3	1	1	2	5	3

4.3.2 Probability terms

As expected, the terms Very unlikely, Unlikely, Likely and Very likely had different (numeric) meanings for each respondent of the survey (Table 4.8). The highest variation was observed in the upper limit (lower limit) of Likely (Very likely) and in the lower limit (upper limit) of Likely (Unlikely). Consequently, the uncertainty associated with the terms Likely and Very likely (and respective IT2FS) was also the highest (Table 4.8).

Table 4.8 Probability terms. Numeric ranges given by eight marine farming operational managers of Golden Bay and/or Tasman Bay and six scientists with experience in aquaculture to the terms Very unlikely, Unlikely, Likely and Very likely. NA: No answer. SD= Standard deviation. Interviewees were asked to indicated both the lowest number (Lower limit) and highest number (Upper limit) they would consider to be defined by each of these terms.

		Probability term							
		Very unlikely		Unlikely		Likely		Very likely	
Responder		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Marine farmer	1	0	20	20	50	50	75	75	100
	2	0	10	10	20	20	70	70	100
	3	0	15	15	20	20	40	40	100
	4	0	25	25	47	47	60	60	100
	5	0	10	10	30	30	60	60	100
	6	0	5	5	15	15	45	45	100
	7	0	10	10	25	25	50	50	100
	8	NA	NA	NA	NA	NA	NA	NA	NA
Scientist	1	0	5	5	15	15	51	51	100
	2	0	5	5	15	15	85	85	100
	3	0	5	5	50	50	75	75	100
	4	0	5	5	20	20	75	75	100
	5	0	10	10	25	25	50	50	100
	6	0	5	5	25	25	50	50	100
	$\bar{X}$	0	10	10	27.5	27.5	60.5	60.5	100
	SD	0	6.5	6.5	13.1	13.1	14.2	14.2	0
Uncertainty		0.9		1.3		2.4		2.7	

4.3.3 Cleaning frequency of aquaculture gear and product

The cleaning pattern reported, varied among marine farmers and aquaculture components. Most farmers (six) reported cleaning the backbone rope while or after harvesting (Table 4.9). The remaining indicated doing it 'when it looks dirty.' While half of the farmers reported cleaning spat and juveniles during the seeding and re-seeding, two indicated doing it 'when it looks dirty', and one 'only if forced to.' One farmer reported never cleaning spat or growing mussels. Similarly, while some farmers reported cleaning buoys while, or after, harvesting, three indicated doing it on a regular basis. All farmers indicated cleaning and sanitising the bags before reusing them, which is one of the food and safety requirements to be certified to export mussels (D. Herbert, pers. comm.).

Components are usually cleaned by the crew on-board (Table 4.9). Culture rope, spat rope and bags may also be cleaned on land. All marine farmers made a clear distinction between the anchors of permanent structures and anchors of seasonal spat catching areas. In seasonal areas all the gear, including anchors, is always removed from the water and stored on land (several months) between seasons. Permanent anchors are very unlikely to be taken out of the water (Table 4.9). None of the famers reported cleaning permanent anchors.

Table 4.9 Cleaning frequency of aquaculture gear and product. Answers of eight marine farming operational managers of Golden Bay and/or Tasman Bay when asked how often they usually clean the indicated aquaculture product and gear. *Permanent anchors.

	Aquaculture component							
When?	Spat	Growing mussels	Backbone rope	Culture rope	Spat rope	Buoys	Anchor*	Bags
Never	1	1					8	
When seeding/ re–seeding	4	4			2			
When it looks dirty	2	2	2	1				
Only if forced to	1							
Always when moved		1						
While/After harvesting			6	3		5		
On regular basis				4	5	3		8
Where?	On–board	On–board	On–board	On–board, land	On–board, land	On–board	--	On–board, land

4.3.4 Movement of gear and product

The likelihood of using aquaculture gear or product that has previously been used in other farms, in their own farms, was described differently among marine farmers (Table 4.10). Most of them (seven), indicated that the movement of backbone ropes and permanent anchors was Very unlikely. Accordingly, the LWA of these answers described the movement of these components as Very unlikely. Also, the uncertainty associated with these answers was the lowest (highest level of agreement) among components (Cr–Cl = 0.96). The LWA of the answers described the movement of all the other components as Likely, with spat rope, growing mussels and buoys having the highest uncertainty (Table 4.10).

Table 4.10 Likelihood of using gear that has been used in other farms. Answers of eight marine farming operational managers of Golden Bay and/or Tasman Bay when asked 'how likely you are to use in your farm aquaculture gear that has been used in farms from other bays/regions.' IDK: I do not know, NA: No answer, Vu: Very unlikely, U: Unlikely, L: Likely, Vl: Very likely, LWA: Linguistic weighted average. Cr–Cl: uncertainty.

	Answers of responders							
Aquaculture component	IDK	NA	Vu	U	L	Vl	LWA	*Cr–Cl*
Growing mussels	0	0	0	1	3	4	Likely	2.21
Spat rope	0	0	0	0	4	4	Likely	2.27
Culture ropes	0	0	3	2	0	3	Likely	1.35
Backbone rope	0	0	7	1	0	0	Very unlikely	0.96
Buoys	0	0	2	0	2	4	Likely	1.84
Anchors (permanent)	0	0	7	1	0	0	Very unlikely	0.96
Scuba–diving gear	1	2	1	0	2	2	Likely	2.05

4.3.5 Water/sediment and fouling retention

Marine farmers and scientists categorised the likelihood of aquaculture gear and product retaining water/sediment or fouling differently (Table 4.11). Most component–infection mode combinations showed a range of answers in both groups, but when their answers were analysed together, the LWA of answers for most of the infection mode–component combinations was Likely (Table 4.11). Only the LWA for the retention of water/sediment and fouling by spat rope, as well as the retention of water/sediment by spat, was Very likely. The LWA for the retention of fouling by SCUBA–diving gear appeared as Unlikely. Similar results were obtained when only farmers were considered, with LWAs varying among Very likely, Likely and Unlikely. In contrast, when the answers of scientists were analysed alone, the LWAs varied only between Very likely and Likely (Table 4.11).

The variation of the probability estimates was the highest in scientists, with an average uncertainty of 2.23, compared to 1.93 for marine farmers and 2.13 for both groups together (Table 4.11). The highest level of disagreement was observed in scientists when assessing water/sediment retention of both culture ropes and spat (uncertainty = 2.70). Similarly, the lowest level of disagreement (highest level of agreement) in all the groups was observed in marine farmers for both infection modes of SCUBA–diving gear. This component had also the highest number of 'I do not know' answers (three farmers), which could explain the high level of agreement.

Table 4.11 Likelihood of aquaculture components to retain water/sediment or fouling when moved between farms. Answers of six scientists and eight marine farming operational managers of Golden Bay and/or Tasman Bay when asked how likely it was for the listed aquaculture components to retain water/sediment (W/S) or fouling (F) when used/taken out the water and transported between farms. Ret.: Retain IDK: I do not know, NA: No answer, Vu: Very unlikely, U: Unlikely, L: Likely, Vl: Very likely, LWA: Linguistic weighted average. Cr–Cl: uncertainty. *Only in specialised vessels. †Anchors from seasonal spat catching equipment.

			Answers of responders							
Group	Aquaculture component	Ret.	IDK	NA	Vu	U	L	Vl	LWA	*Cr–Cl*
Marine Farmers	Spat	W/S	0	0	1	0	2	5	Very likely	2.40
		F	0	0	0	1	4	3	Likely	2.37
	Growing mussels	W/S	0	0	1	0	2	5	Very likely	2.40
		F	0	0	0	1	4	3	Likely	2.37
	Spat rope	W/S	0	0	1	0	2	5	Likely	2.40
		F	0	0	0	0	4	4	Very likely	2.27
	Culture rope	W/S	0	0	1	1	2	4	Likely	2.08
		F	0	0	0	1	4	3	Likely	2.37
	Buoys	W/S	0	0	2	1	1	4	Likely	1.97
		F	0	0	1	1	2	4	Likely	2.27
	Anchors†	W/S	0	1	2	1	0	4	Likely	2.02
		F	0	1	2	1	0	4	Likely	2.02
	Declumping Equipment*	W/S	0	0	1	3	1	3	Likely	1.66
		F	0	0	2	3	1	2	Likely	1.60
	Seeding equipment*	W/S	0	0	2	4	0	2	Likely	1.50
		F	0	0	2	5	0	1	Unlikely	1.35
	Bags	W/S	0	0	1	4	0	3	Likely	1.58
		F	0	0	1	4	1	2	Likely	1.69
	SCUBA–diving gear	W/S	3	0	3	1	0	1	Unlikely	1.16
		F	3	0	3	1	0	1	Unlikely	1.16

			Answers of responders							
Group	Aquaculture component	Ret.	IDK	NA	Vu	U	L	Vl	LWA	*Cr–Cl*
Scientists	Spat	W/S	0	0	0	0	2	4	Very likely	2.70
		F	0	0	0	0	1	5	Very likely	2.22
	Growing mussels	W/S	0	0	0	1	1	4	Very likely	2.20
		F	0	0	0	0	1	5	Very likely	2.22
	Spat rope	W/S	0	0	0	0	1	5	Very likely	2.22
		F	0	0	0	0	1	5	Very likely	2.22
	Culture rope	W/S	0	0	0	0	2	4	Very likely	2.70
		F	0	0	0	0	1	5	Very likely	2.22
	Buoys	W/S	0	0	0	3	2	1	Likely	1.82
		F	0	0	0	0	1	5	Very likely	2.22
	Anchors†	W/S	0	1	0	1	1	3	Likely	2.56
		F	0	1	0	1	2	2	Likely	2.13
	Declumping Equipment*	W/S	1	0	0	1	2	2	Likely	2.13
		F	1	0	0	0	3	2	Likely	2.42
	Seeding equipment*	W/S	2	0	0	1	2	1	Likely	2.13
		F	2	0	0	1	2	1	Likely	2.13
	Bags	W/S	2	0	0	1	1	2	Likely	2.19
		F	2	0	0	1	2	1	Likely	2.13
	SCUBA–diving gear	W/S	0	0	0	0	2	4	Very likely	2.13
		F	0	0	0	3	3	0	Likely	1.82
Marine farmers and scientists	Spat	W/S	0	0	1	0	4	9	Very likely	2.53
		F	0	0	0	1	5	8	Likely	2.48
	Growing mussels	W/S	0	0	1	1	3	9	Likely	2.58
		F	0	0	0	1	5	8	Likely	2.48
	Spat rope	W/S	0	0	1	0	3	10	Very likely	2.22
		F	0	0	0	0	5	9	Very likely	2.55
	Culture rope	W/S	0	0	1	1	4	8	Likely	2.41
		F	0	0	0	1	5	8	Likely	2.48
	Buoys	W/S	0	0	2	4	3	5	Likely	1.82
		F	0	0	1	1	3	9	Likely	2.58
	Anchors†	W/S	0	2	2	2	1	7	Likely	2.28
		F	0	2	2	2	2	6	Likely	2.04
	Declumping Equipment*	W/S	1	0	1	4	3	5	Likely	1.84
		F	1	0	2	3	4	4	Likely	2.04
	Seeding equipment*	W/S	2	0	2	5	2	3	Likely	1.70
		F	2	0	2	6	2	2	Likely	1.55
	Bags	W/S	2	0	1	5	1	5	Likely	1.78
		F	2	0	1	5	3	3	Likely	1.83
	SCUBA–diving gear	W/S	3	0	3	1	2	5	Likely	1.77
		F	3	0	3	4	3	1	Unlikely	1.59

(Table 4.11 continued)

4.3.6 Probability of cleaning aquaculture components when moved

As with the likelihood of retention, marine farmers and scientists provided different estimates for the likelihood of cleaning aquaculture components when moved between farms (Table 4.12). The LWA of the answers given by marine farmers varied mainly between Very likely and Likely although the LWA for anchors was Unlikely. In contrast, with scientists the LWA varied only between Unlikely and Likely (Table 4.12). When the answers of marine farmers and scientists were analysed together, the LWA for all the components was Likely (Table 4.12). The highest uncertainty was associated with culture (2.76) and spat (2.19) rope in the marine farmers group. These components showed also the highest uncertainties when marine farmers and scientists were considered together (4.12).

All marine farmers indicated that they followed in–house guidelines and 'common sense' when moving and cleaning aquaculture components. Four of them also indicated following the Greenshell Mussel Industry Environmental Code of Practice (Aquaculture New Zealand 2007).

Table 4.12 Likelihood of cleaning aquaculture components before deploying them in marine farms. Answers of six scientists and eight marine farming operational managers of Golden Bay and/or Tasman Bay when asked how likely the indicated aquaculture components were cleaned between farms. IDK: I do not know, NA: No answer, Vu: Very unlikely, U: Unlikely, L: Likely, Vl: Very likely, LWA: Linguistic weighted average

		Answers of responders							
Group	Aquaculture component	IDK	NA	Vu	U	L	Vl	LWA	Uncertainty
Marine farmers	Spat	0	0	4	1	1	2	Likely	1.43
	Growing mussels	0	0	3	1	1	3	Likely	1.51
	Spat rope	0	0	1	0	1	6	Very likely	2.19
	Culture rope	0	0	0	1	0	7	Very likely	2.76
	Buoys	0	0	0	2	1	5	Very likely	2.09
	Anchors†	0	1	2	1	0	4	Very unlikely	0.92
	Declumping equipment	0	0	2	2	0	4	Likely	2.06
	Seeding equipment	0	0	2	2	0	4	Likely	2.02
	Bags	0	0	3	1	1	3	Likely	1.53
	Scuba–diving gear	3	1	2	0	0	2	Likely	1.44
Scientists	Spat	2	0	1	2	1	0	Unlikely	1.45
	Growing mussels	2	0	1	1	1	1	Likely	1.71
	Spat rope	3	0	1	0	2	0	Likely	1.89
	Culture rope	3	0	2	0	0	1	Likely	1.16
	Buoys	1	0	2	1	2	0	Unlikely	1.57
	Anchors†	1	0	1	3	1	0	Unlikely	1.43
	Declumping equipment	1	0	1	2	2	0	Unlikely	1.63
	Seeding equipment	2	0	1	2	1	0	Unlikely	1.45
	Bags	3	0	1	2	0	0	Unlikely	1.17
	Scuba–diving gear	1	0	2	2	1	0	Unlikely	1.38
Marine farmers and scientists	Spat	2	0	5	3	2	2	Likely	1.47
	Growing mussels	2	0	4	2	2	4	Likely	1.85
	Spat rope	3	0	2	0	3	6	Likely	2.06
	Culture rope	3	0	2	1	0	8	Likely	2.01
	Buoys	1	0	2	3	3	5	Likely	1.81
	Anchors†	1	3	3	4	1	2	Likely	1.39
	Declumping equipment	1	0	3	4	2	4	Likely	1.84
	Seeding equipment	2	0	3	4	1	4	Likely	1.60
	Bags	3	0	4	3	1	3	Likely	1.58
	Scuba–diving gear	4	1	4	2	1	2	Likely	1.35

4.3.7 Estimate differences between marine farmers and scientists

Except for the cleaning of culture rope (χ^2= 7.7049, *p*= 0.024) and bags (χ^2= 7, *p*= 0.031), as well as the retention of water/sediment by Scuba–diving gear (χ^2= 7.5429, *p*= 0.0152), there were no statistically significant differences (p > 0.05) between the likelihood estimates of marine farmers and scientists.

4.3.8 Potential vectors and risk-ranking

Although aquaculture vessels were not specifically analysed in this study, the information collected indicated that there are at least 14 vessels used in the NZGM aquaculture in the study region that range from large and relatively slow harvesting and seeding vessels, to small and fast sourcing and inspecting boats. Most of these vessels serve not only different farms within Golden Bay and Tasman Bay, but also different farms within the Marlborough Sounds, and occasionally even aquaculture regions in the North Island.

As expected the risk ranking of aquaculture sub-vectors varied depending on the likelihood estimates used (Table 4.13). In general, the risk ranking conducted based only on the likelihoods (i.e., retention, movement, cleaning) given by marine farmers, or on the combination of the likelihoods given by marine farmers and scientists, were consistently more conservative (i.e., lower) than those estimated when using only the likelihoods from scientists. For example, while the risk rank assigned to culture rope, declumping and seeding equipment, bags, buoys, and Scuba–diving gear was High when using only information from scientists, the same sub-vectors were risk-ranked as either Medium or Low when using information from only marine farmers or from the combination of marine farmers and scientists. Only the risk rank for sub-vectors spat and anchors was consistently classified as High and Low, respectively, regardless of the likelihood estimates used.

4.3.9 Potential interactions with other pathways

The present study identified that the NZGM aquaculture could potentially interact in Golden Bay and Tasman Bay directly with five NIS pathways: 1) commercial and recreational vessels, 2) live seafood, 3) public aquaria, 4) research, and 5) coastal currents (Table 4.13., Figs. 4.1 and 4.2).

4.3.9.1 Commercial shipping and fishing, and recreational boating

Port Tarakohe and Port Nelson are used by aquaculture vessels as well as cargo and fishing vessels (Hayden et al. 2009, Stuart et al. 2009). These areas also have marinas and boat ramps that are commonly used by recreational vessels. Similarly, a survey conducted among recreational boat users in Golden Bay and Tasman Bay showed that some recreational vessels visit marine farms during their cruising (Chapter 3).

4.3.9.2 Live seafood

Live mussels are commonly sold in supermarkets throughout Golden Bay and Tasman Bay. Similarly, there are at least two restaurants with seawater tanks where they keep live seafood, which can include NZGM (pers. obs.).

4.3.9.3 Public aquaria

The only public aquarium open in recent times was located in Mapua. This aquarium used to get NZGM for display and as a food source for other specimens (M. Goss, pers. comm.) (Figs. 1.2 and 4.1). The aquarium was destroyed by a fire after this study was conducted

(Harper 2011), which eliminated this interaction. However, current plans to rebuild it mean that the interaction could be restored.

Table 4.13 Risk-ranking for NZGM aquaculture sub-vectors. Rank assigned based on a predefined lookup risk-rank table (Table 4.2) combining the likelihoods of the vector: 1) retaining fouling or water/sediment, 2) being moved between farms, 3) being cleaned when moved. When the likelihoods of retaining water/sediment and retaining fouling differed for the same sub-vector, the precautionary principle was applied and the highest likelihood (highlighted on gray in the table) between them was used to estimate the risk. As backbone ropes were never moved between farms, no likelihood of retention or cleaning was estimated for this vector.

Stakeholder	Component	Likelihood of				Risk
		Retention of				
		Water/Sediment	Fouling	Movement	Cleaning	
M. Farmers	Spat	Very likely	Likely	Very likely	Likely	High
Scientists		Very likely	Very likely		Unlikely	High
Both		Very likely	Likely		Likely	High
Farmers	Growing mussels	Very likely	Likely	Likely	Likely	Medium
Scientists		Very likely	Very likely		Likely	Medium
Both		Likely	Likely		Likely	Low
M. Farmers	Spat rope	Likely	Very likely	Likely	Very likely	Low
Scientists		Very likely	Very likely		Likely	Medium
Both		Very likely	Very likely		Likely	Medium
M. Farmers	Culture Rope	Likely	Likely	Likely	Very likely	Low
Scientists		Very likely	Very likely		Likely	Medium
Both		Likely	Likely		Likely	Low
M. Farmers	Backbone Rope	--	--	Very unlikely	--	Low
Scientists		--	--		--	
Both		--	--		--	
M. Farmers	Buoys	Likely	Likely	Likely	Very likely	Low
Scientists		Likely	Very likely		Unlikely	High
Both		Likely	Likely		Likely	Low
M. Farmers	Anchors†	Likely	Likely	Very unlikely	Very unlikely	Low
Scientists		Likely	Likely		Unlikely	Low
Both		Likely	Likely		Likely	Low
M. Farmers	Declumping equipment^	Likely	Likely	Very likely	Likely	Medium
Scientists		Likely	Likely		Unlikely	High
Both		Likely	Likely		Likely	Medium
M. Farmers	Seeding equipment^	Likely	Unlikely	Very likely	Likely	Medium
Scientists		Likely	Likely		Unlikely	High
Both		Likely	Likely		Likely	Medium
M. Farmers	Bags	Likely	Likely	Very likely	Likely	Medium
Scientists		Likely	Likely		Unlikely	High
Both		Likely	Likely		Likely	Medium
M. Farmers	SCUBA–diving gear	Unlikely	Unlikely	Likely	Likely	Low
Scientists		Very likely	Likely		Unlikely	High
Both		Likely	Unlikely		Likely	Low

4.3.9.4 Research

Informal interviews with four research companies (which included the three companies that participated in this study) showed that they are likely to conduct fieldwork in Golden Bay and Tasman Bay at least twice a year. The fieldwork can be related to aquaculture, environmental monitoring, biosecurity, fisheries, and scientific research, and include a range of gear such as bottom–grab samplers, water samplers, traps/pots/cages, dredges and SCUBA–diving gear. Some of this gear is very likely to be cleaned in the field (e.g., at boat ramps, marine farms, on board vessels). This means that gear could act as a vector for NIS if it is not cleaned at the site where it was last used.

Table 4.14 Interaction of the NZGM industry with other potential NIS pathways present in Golden Bay and Tasman Bay.

Pathway	Vector	Mechanism
Commercial shipping and fishing, and recreational boating	Vessels	Commercial and recreational vessels interact with both: 1) vessels used for aquaculture, and 2) structures used by these vessels (e.g., wharves, marinas, marine farms).
Live seafood	Mussels, and transporting and packaging material.	Vector moved from marine farms to processing plants, supermarkets and restaurants with seawater tanks.
Public aquaria	Mussels, and transporting and packaging material	Vector brought into the tanks of the public aquaria.
Research	Spat and mussels, transporting and packaging material, and sampling gear (including SCUBA–diving gear).	Vectors moved between farms and research facilities.
Coastal currents	Aquaculture debris and propagules	Vector transported by coastal currents to 1) other areas in the region and 2) among marine structures (e.g., marine farms, wharves, boat ramps).

Three of the companies have seawater facilities in the study region but only two of them actually use them (Fig. 4.1). These companies bring NZGM spat and live specimens from mussel farms off Golden Bay and Tasman Bay into their facilities for aquaculture related (and non-related) research. One of these facilities includes a hatchery that can produce commercial quantities of NZGM spat (Figure 4.1). Spat from this hatchery is normally used in the neighbouring region of the Marlborough Sounds, but sometimes it is also used in Golden Bay and Tasman Bay (see section 4.3.1).

4.3.9.5 Coastal currents

The results of a tidal advection model that simulated particle dispersion from selected marine farms in Golden Bay and Tasman Bay over a 24–hour period suggested that pathogens could spread to neighbouring farms within a certain distance (Morrisey et al. 2011). Similarly, the results of a Lagrangian model that simulated propagule dispersal in Golden Bay and Tasman Bays using 13 years of real meteorological data, suggest that currents are likely to interconnect most of the areas in the study region (Chapter 6). Therefore, mussel spat catching and growing farms that appeared geographically separated (e.g., Golden Bay and Croisilles Harbour, Figs. 1.2 and 4.1) could eventually be connected by coastal currents.

4.4 DISCUSSION

4.4.1 Conceptual Model

NZGM aquaculture has been previously modelled simply as the process of spat collecting, seeding, harvesting and product transport to processing plants (e.g., Hickman 1976, Jeffs et al. 1999). Although this basic description is an accurate representation for general purposes, from an NIS risk assessment point of view it is vague and does not allow a clear identification of components and processes. Other studies (e.g., Forrest and Blackmore 2002, Dodgshun et al. 2007, Keeley et al. 2009, Morrisey et al. 2011) have identified the pathways of NZGM aquaculture within New Zealand, but their national focus limits their value as baseline information for comprehensive biosecurity risk assessments of the NZGM industry in Golden Bay and Tasman Bay. All these studies for example, do not differentiate the specific areas involved in the movement of spat among Golden Bay, Tasman Bay, and the Marlborough Sounds.

The conceptual model developed here, in contrast, gives a detailed representation of the NZGM aquaculture process in Golden Bay and Tasman Bay, identifying components, vectors, and interactions with other pathways that might be key in the spread of marine NIS via this industry. The model makes it evident that NZGM aquaculture in Golden Bay and Tasman Bay is a complex and extensive network that virtually connects (by road and by sea) the entire region (Figs. 1.2 and 4.1).

The introduction of artificial surfaces in intertidal and relatively shallow subtidal areas creates novel habitats in the environment (Bulleri and Chapman 2010). Marine farms in particular provide habitat for fouling organisms and their associated biota (Costa-Pierce and Bridger 2002, Dumbauld et al. 2009); organisms and biota that can be both native and non-native. In the study region for example, *U. pinnatifida* has been found established in mussel farms in Golden Bay (Wainui Bay) and Tasman Bay (Croisilles Harbour) (Forrest and Blakemore 2002, McClary and Stuart 2004). Similarly, in the Marlborough Sounds, NIS species such as *C. intestinalis* and *M. galloprovincialis*, as well as *U. pinnatifida* and *D. vexillum* (Keeley et al. 2009) have been found associated with the mussels and structures of holding and growing farms. This clearly demonstrates that marine farms in the study region have the potential to act as NIS introduction and spread nodes within the NZGM aquaculture pathway.

The structures of spat catching farms are comprised of the same components of those present in mussel holding and growing farms (e.g., buoys, ropes, anchors). This means they also offer complex habitats for the colonisation of fouling organisms and associated biota, which can include NIS. In Tasman Bay these structures are only in the water during the spat season, preventing the establishment of permanent NIS populations. They could still act as stepping stone populations (Wright 1943, Slatkin 1993, Apte et al. 2000, Keller et al. 2011) and facilitate the spread of NIS into nearby areas. In particular, their close proximity to highly valued areas such as the Abel Tasman National Park and the Tonga Island Marine Reserve could pose significant risk if spat catching structures are colonised by NIS (Figs. 1.2 and 4.1).

In the present model components such as hatcheries and research facilities, not considered in previous studies (e.g., Forrest and Blackmore 2002, Keeley et al. 2009), can be readily identified as potential NIS infection sources or cross-contamination scenarios, where management might be required. The potential role of these facilities in the incubation and spread of diseases within aquaculture industries has long been demonstrated (e.g., Bower et al. 1994, Muroga 2001, Renault and Arzul 2001). For example, hatcheries were linked to the inadvertent introduction and spread of the NIS sabellid polychaetes *Terebrasabella heterouncinata* to California, US, via abalone seed stock from South Africa (Kuris and Culver 1999, Culver and Kuris 2000, 2004). Hatcheries and research facilities are likely to have a controlled environment (e.g., temperature, food supply) which could facilitate the survival of NIS within these facilities. Hence, depending on their interactions with marine farms and the biosecurity measures in place, these facilities could become an important component in the NZGM pathway in the study region and other mussel farming regions across New Zealand (e.g., Marlborough Sounds, Coromandel peninsula) for the spread of NIS.

Spat cleaning facilities are not currently used in the study region, but they could easily become active if new blooms of toxic microalgae in Kaitaia or the Marlborough Sounds are detected, making the cleaning of spat necessary. The spat cleaning method is considered very effective at isolating the mussel spat (M. Taylor, pers. comm.), which facilitates the handling, and more importantly, discharge of remaining biosecurity hazards. The requirement of resource management consent from a regional council, as indicated by the New Zealand Coastal Policy Statement 2010 (DoC 2010), would ensure that effective measures that reduce the likelihood of releasing biosecurity hazards, such as toxic algae and NIS, into the environment are in place. The role of spat cleaning facilities in the spread of NIS could therefore be considered limited (if not negligible).

The present model also highlights the overlapping (interaction) of the NZGM with other identified potential NIS pathways in Golden Bay and Tasman Bay such as natural currents, commercial shipping, recreational boating, live seafood trade, public aquaria and research. Such overlapping is likely to expand the range of influence of NZGM aquaculture as a pathway for NIS within the study region. Interaction between commercial and recreational vessels in ports and marinas is well recognised, and this is why these areas are usually considered as potential hubs for the spread of NIS (Bax et al. 2002, Kinloch et al. 2003, Glasby et al. 2007, Sinner et al. 2009)

Public aquaria have been also identified as potential pathways for the spread of NIS (Carlton 2001). There is no public aquarium at the moment (at time of writing) in the study region, but plans to rebuild one in Mapua could reintroduce this pathway into the area. As with hatcheries, tanks in public aquaria offer a controlled environment (e.g., temperature, salinity, food supply) to ensure the survival of display organisms. This is also likely to favour the survival and establishment of NIS organisms with habitat requirement similar to the display organisms'. Freeing organisms with short life expectance in captivity (e.g., sharks) directly into the environment is a common practice in New Zealand public aquaria (M. Goss, pers. comm.). This practice could then inadvertently release NIS organisms or propagules from the tanks into the environment.

Aquarium water discharges (effluents) have also the potential to release NIS into the environment. The spread of the highly invasive seaweed *Caulerpa taxifolia* is perhaps the most cited example for such pathway (e.g., Meinesz et al. 1995, Sant et al. 1996, Jousson et al. 1998, Komatsu et al. 2003, Anderson 2005) but there are other species (not usually considered to be related to the aquarium pathway) that have also demonstrated the feasibility of this mechanism. For example, in Cape Town (South Africa), the small red alga *Schimmelmannia elegans* has only been recorded in the 'Kelp Tank' of a public aquarium and growing below an outlet pipe where the water from this aquarium is discharged into the harbour (DeClerk et al. 2002). Similarly, a pilot study in the same aquarium caught several specimens of the invasive European crab *Carcinus maenas* at one of the effluents to the sea (S. Voughn, pers. comm.). Although it was international hull fouling the most likely introduction pathway for these species (Robinson et al. 2005), the presence of these introduced species in the aquarium tanks, discharged effluents, and neighbouring areas, demonstrates the important role that public aquaria can have in the spread of NIS.

4.4.2 Sub-vector and risk ranking

Aquaculture vessels have been identified as vectors for the spread of NIS (Galil 2008, Gust et al. 2008, Herborg et al. 2009). The likelihood of spreading NIS via vessels, specifically via biofouling, is known to depend on several variables such as vessel type, cruising speed, and hull husbandry (Floerl et al. 2005a, Davidson et al. 2006, Coutts et al. 2010, Inglis et al. 2010). Therefore, although they were not specifically considered in this study (except for declumping and seeding equipment of specialised vessels), the probability of entraining, transporting and releasing NIS within the study region is likely to vary considerably among aquaculture vessels and their sub-vectors depending on the type, operational characteristics, maintenance and cleaning habits (Table 4.1). In the farms for example, during seeding and harvesting there is a repeated (sometimes continuous) significant contact between the hulls of visiting vessels and aquaculture gear and product (e.g., when retrieved/deployed the ropes and product slide against the hull, usually scratching, above and below the waterline of the vessels (pers. obs.)). This makes cross-contamination between these sub-vectors probable, and indicates that the spread of NIS associated with hull fouling (e.g., colonies and propagules of *D. vexillum*, Lengyel et al. 2009) and aquaculture gear fouling (e.g., individuals of *S. clava*, Le Blanc et al. 2007, Locke et al. 2007, fragments of *U. pinnatifida*, Forrest and Blackmore 2006) is possible.

A similar situation occurs when sub-vectors deck and internal spaces are considered. Most aquaculture gear and product is transported, and more importantly, cleaned on the deck of the vessels (Table 4.9), creating a potential cross-contamination scenario. It is a common practice, generally authorised under a resource consent[13] (Aquaculture New Zealand 2007), to discharge cleaning residues (sediment, fouling and washwater) overboard (Table 4.9). If viable propagules or intact organisms of already established (e.g., *C. intestinalis*) or potential NIS aquaculture pests are present in such residues, this could be an effective spread mechanism within farming regions for these species. Similarly, interaction between the environment and internal spaces such as bilges and seawater inlet/outlets (e.g., viable NIS propagules or intact organisms can be discharged into the bilge via washwater, Chapter 2) might be frequent during harvesting and seeding activities, generating situations that favour NIS entrainment or release. In contrast, it is uncommon for seeding and harvesting vessels to lay anchor in farming areas (M. Holland, pers. comm.), and thus, the interaction of the anchor with aquaculture gear and product, as well as with marine farms' environment, is generally limited.

Routine aquaculture operations in Golden Bay and Tasman Bay include transfer of spat, mussels and gear among farming bays and regions (Figs. 4.1 and 4.2). The results of the present study show that, in addition to aquaculture vessels, a range of aquaculture components could act as sub-vectors for the introduction and spread of NIS in the study region (Tables 4.1, 4.11–4.14). However, the frequency of movement, likelihood of retaining water/sediment and fouling, likelihood of cleaning between farms, and thus NIS spread risk, seem to vary among these sub-vectors (Tables 4.11–4.14). Although the present assessment stems from expert opinion and thus more research is required for decision-making processes based on quantitative data, it provides valuable baseline information while such data are gathered. The estimated risk for spat was consistently classified as High using either data from scientists, from marine farmers, or from both groups combined. These results suggest that spat movement should be considered a biosecurity priority and key element in management efforts such as the implementation of codes of conduct and guidelines (e.g., Aquaculture New Zealand 2007), research initiatives, and education campaigns among stakeholders. Other sub-vectors with High–Medium risk estimates such as declumping and seeding equipment should be also managed, and their potential role to spread NIS investigated in more detail.

As with any model and expert-elicited data, the present study includes a range of uncertainties. An important source of uncertainty is the lack of input from 'small' marine farmers. Although it is estimated that the companies included in the survey covered ca. 90% of the NZGM industry in Golden Bay and Tasman Bay, biosecurity practices among small operators may differ (K. Heasman, pers. comm.) and thus, the results might have varied had representatives of this group participated in the survey. Similarly, answers from both scientists and marine farmers are likely to have been influenced by several heuristics and cognitive biases. By asking experts to critically analyse the model of the NZGM aquaculture, the study

[13] A permit issued by a local or regional government agency for activities that may affect the environment.

encouraged them to base their answers on factual and accurate information. It is possible however, that interviewers have ignored this information and used heuristic methods such as anchoring and availability (Kahneman and Tversky 1973, 1979, Kahneman et al. 1982) (see discussion Chapter 3) when providing estimates of probabilities.

When invited to participate, all participating people were informed that the project was related to marine biosecurity (Appendix C.1). Both motivational (Lord et al. 1979, Srull and Wyer 1986) and accountability (Weigold and Schlenker 1991, Lerner and Tetlock 1999, Tetlock 1983, 1992) biases might have affected the answers of the interviewees. In expert opinion data gathering the analyst must be aware that these two aspects will always be an important part of evaluating probabilities (Aven 2003). In this study it is possible that while scientists wanted to stress the potential role of aquaculture in the spread of NIS, marine farmers were trying to portray their practices as 'harmless' as possible from a biosecurity point of view. This could explain the likelihood assessment differences observed between the groups.

Risk perception is well-known to vary among people (Slovic 1964, Weber 1988, Slovic et al. 1986, Slovic 1987), with some being risk-averse and other risk-takers (e.g., Slovic et al. 1982, von Winterfeldt and Edwards 1986, Cooper et al. 1988). The risk ranking table created by the author, and used to classify aquaculture sub-vectors, would be certainly influenced by his perception of the risk. However, by describing the method followed and presenting the assumptions used, the risk ranking process can be analysed, evaluated, and changed if required, and the model and likelihood estimates would still be valuable information for risk assessments and/or management decisions.

4.5 CONCLUSIONS

The NZGM aquaculture in Golden Bay and Tasman Bay is a complex network that interconnects most of this region. Such a network can be modelled as a 10-component system that includes: 1) spat catching sites, 2) holding sites, 3) growing sites, 4) wharves, 5) processing plants, 6) gear cleaning facilities, 7) research facilities, 8) hatcheries, 9) spat cleaning facilities, and 10) land storages. Most of the spat in the study region comes from Kaitaia, but some is from permanent spat catching sites in Wainui Bay and seasonal spat catching sites in the eastern side of Tasman Bay. In addition to spat, other potential sub-vectors such as growing mussels, aquaculture gear and vessels are moved among the components of the system creating a pathway for the spread of NIS within the region. The NZGM aquaculture in Golden Bay and Tasman Bay interacts with other regions across New Zealand (e.g., Marlborough Sounds, Coromandel and Northland) creating an avenue for the introduction and spread of NIS among aquaculture regions in New Zealand.

The estimated probabilities of: 1) being moved among components, 2) retaining water, sediment and/or fouling, and 3) being cleaned when moved between components, varied among aquaculture sub-vectors. Such probabilities also varied depending on the expert source used in the assessment (i.e., marine farmers vs. scientists). The estimated risk for spat nonetheless was consistently considered High regardless of the data source used. Also, the estimated risk for declumping equipment, seeding equipment, and bags, was comparatively higher, varying between High and Medium. Hence, these four sub-vectors should be considered biosecurity research and management priorities in the study region.

The complexity of the NZGM aquaculture network in Golden Bay and Tasman Bay increases when overlaps with other potential NIS pathways are considered. Potential and realised interactions with commercial shipping, recreational boating, live seafood, public aquaria, research, and natural currents are likely to enhance the spatial range of influence of the NZGM aquaculture as a pathway for NIS in this region. Although more specific information and quantitative data are required, the present study provides valuable information that could assist managers to prioritise research, design codes of conduct, and implement management approaches, not only in the study region, but also in other regions across New Zealand and overseas.

Chapter 5: Natural dispersal of marine non-indigenous species

5.1 INTRODUCTION

Preventing the human-mediated spread of marine non-indigenous species (NIS) through effective border control is widely regarded as the best approach to slow the escalation of the NIS problem (Meyerson and Reaser 2002, Simberloff 2003, Hewitt and Campbell 2007). However, the inevitable arrival of new species, or the continued spread of established pests, means that strategies to contain ongoing spread via management of human-mediated pathways are also desirable (Hewitt et al. 2004, Forrest et al. 2009). These pathways include, among others, commercial (Gollasch 2002, Godwin 2003, Boltovskoy et al. 2011, Sylvester et al. 2011) and recreational (Floerl and Inglis 2005, Mineur et al. 2008, Clarke Murray et al. 2011) vessel movements, aquaculture and fishing industry activities (Naylor et al. 2001, Minchin 2007a), and the aquarium trade (Komatsu et al. 2003, Semmens et al. 2004).

The benefit of managing human-mediated pathways depends greatly on the likelihood and time-scale over which NIS can spread by natural mechanisms, particularly the dispersal of planktonic propagules, such as algal spores and invertebrate larvae by water currents. Managing anthropogenic vectors to prevent the transport of NIS between coastal areas is likely to be pointless where there is a high likelihood of an uncontrolled invasion in the short-term as a result of the natural dispersal of such species (Elston 1997, Forrest et al. 2006). Conversely, where barriers to natural dispersal arise, it may be possible to identify ‘internal borders’ around which human-mediated pathways of spread can be managed, and associated pest management activities (e.g., surveillance, incursion response) undertaken (Forrest et al. 2009). Therefore, knowledge of the connectivity of coastal regions resulting from natural dispersal of propagules by water currents is integral to understanding the likely efficacy of vector management.

A range of methods have been used to understand coastal connectivity and the natural dispersal of marine pest species and other organisms, including direct field assessment of propagule dispersal, inference from studies of genetic connectivity and species distributional patterns, and predictions from spread modelling (e.g., Forrest et al. 2000, Kinlan and Gaines 2003, Siegel et al. 2003, Kinlan et al. 2005, Gaines et al. 2007). Modelling approaches have particular appeal in the context of invasive species, as the spread of potential pest organisms from point sources of infestation (e.g., hubs of human activity such as ports) is often of primary interest (e.g., MacIsaac et al. 2004, Floerl et al. 2009) to understand the dynamic of the invasions, forecast (and backcast) the spread of invasion, and conduct risk assessments. In this respect, models can be used to highlight relative differences in dispersal in relation to species attributes (e.g., planktonic propagule duration (PPD)) and supply-side attributes (e.g., invader density or frequency of propagule release). Furthermore, models can be used to identify timescales of spread and habitats or values at-risk, based on likely patterns of invader dispersal.

In marine environments, particle dispersion[14] models have been used in several fields, such as pollution assessment and monitoring (e.g., Cetina et al. 2000), larval dispersal (e.g., Edwards et al. 2007), population recruitment, dynamics and connectivity (e.g., Roberts 1997, Cowen et al. 2000, James et al. 2002, Kinlan et al. 2005, Cowen et al. 2006), and also in the design of marine reserve networks (Shanks et al. 2003). Conversely, published models for the dispersal of marine NIS by natural currents are limited to a few examples throughout the world (e.g., McQuaid and Phillips 2000, Johnson et al. 2005, Byers and Pringle 2006, Brickman and Smith 2007), and are often based on short time series. Nevertheless, from a management perspective, dispersal and connectivity over relatively longer time scales (e.g., years) is generally of more relevance. Such scales are more likely to integrate all dispersal processes, reveal temporal variations, and thus, provide more accurate patterns (Jacobson and Peres-Neto 2010); essential for (better) informed biosecurity decisions.

The objective of the present study was to identify the dispersal and connectivity patterns generated by surface currents across a range of planktonic propagule durations (PPD) in Golden Bay and Tasman Bay, New Zealand (Figs. 1.2 and 5.1). For this, a Lagrangian particle-tracking model and a regional hydrodynamic current model were combined. This study included 13 years of hourly data to simulate the dispersal of planktonic propagules from point sources in these bays. These simulations were used in conjunction with existing and new methods to derive dispersal parameters (advection and spread measures), and describe the connectivity of coastal areas in the study region in relation to PPD. The results were used to illustrate the importance of understanding spatio-temporal patterns of natural dispersal within the context of invasive species management.

5.2 MATERIALS AND METHODS

Most natural dispersal studies combine regional hydrodynamic current models and Lagrangian particle-tracking models. The first model simulates physical properties (e.g., current, salinity and temperature), while the particle-tracking model simulates transport, which is the result of advection, dispersion and diffusion. In order to study the potential role of water currents in the dispersal of marine NIS within the study region, a decoupled two-dimensional (2D) advection-diffusion model was used to simulate the dispersion of passive particles. The release point of these particles was varied along the coastline, and different dispersion patterns were identified. Likewise, the effect of the life span of the particles on dispersion patterns was investigated. Biological components, such as mortality, settlement, or vertical migration were not considered, and it was assumed that the same number of propagules (particles) remained in the

[14] In order to be consistent with its meaning in the field of oceanography, when used to refer to the actual model or modelling process, dispersion means the spreading of particles from a source point (Marion 2008, Thorpe 2009). Otherwise, dispersion follows the concept used in ecology that refers to the way in which individuals (propagules in this particular case) are arranged in space, relative to each other (Haag and Tom 1998, Karleskint et al. 2011).

surface layer. The advection-diffusion model consisted of two main components: 1) a hydrodynamic module (deterministic), and 2) an advection-diffusion module (stochastic).

5.2.1 Hydrodynamic model

A validated three-dimensional (3D) numerical model that simulates hydrodynamic flows within the study region at five depth categories and at a resolution of 2.5 km2, which was developed using the Environmental Fluid Dynamics Computer Code (EFDC, Hamrick 1992), is described by Tuckey et al. (2006). The EFDC uses the numerical schemes from the Princeton Ocean Model (Blumberg and Mellor 1987), and solves the 3D, vertically hydrostatic, free surface, turbulent averaged equations for a fluid of variable density. The EFDC also solves dynamically coupled transport equations for turbulent kinetic energy (TKE), turbulent length scale, salinity, and temperature (see Hamrick 1992 and Tuckey et al. 2006, for details).

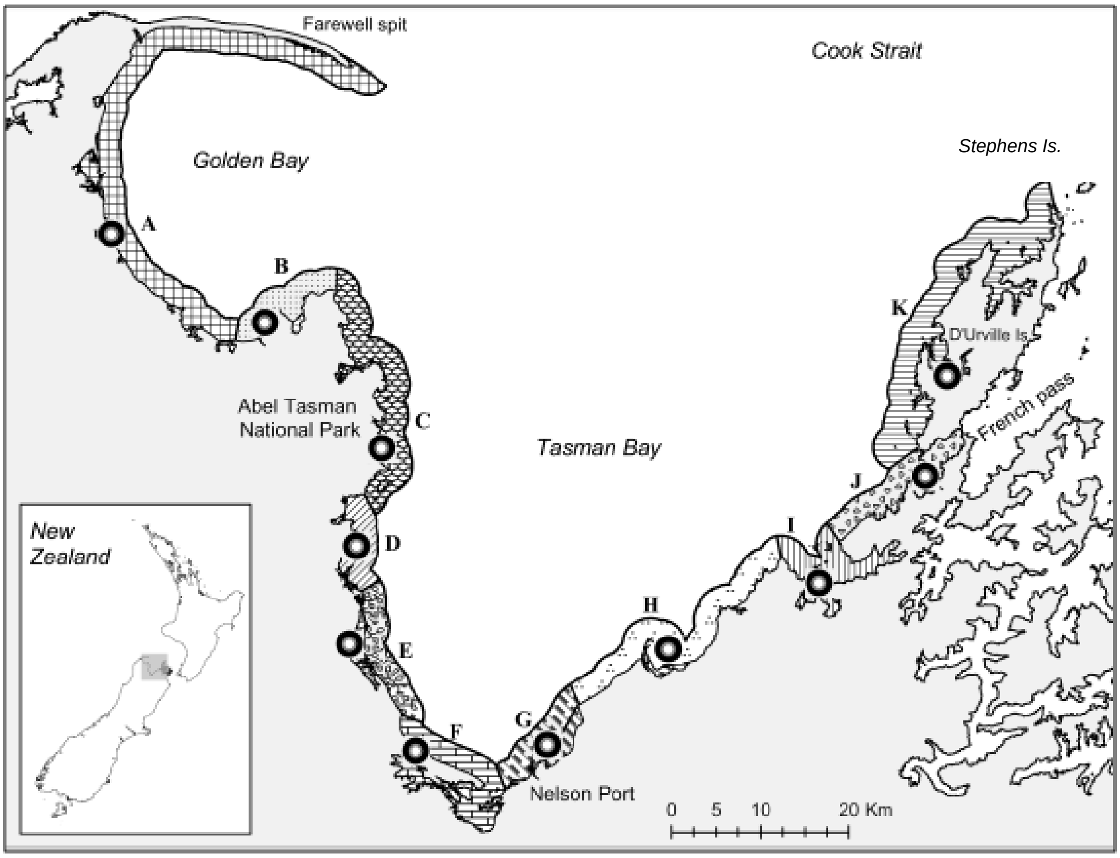

Figure 5.1 Golden Bay and Tasman Bay, New Zealand. The study region was subdivided into 11 sub-regions labelled from A to K, which are represented by different 'shading' patterns along the coastline. Black and white circles represent the locations used as release points for the simulations.

The use of 3D hydrodynamic models to simulate marine current fields has advantages over 2D models. They usually include vertical density gradients and hence partition energy and transport in a physically realistic manner. Similarly, dispersal models based on 3D hydrodynamic models can incorporate diel migration present in some marine organisms (e.g., Orlov 1997, Leys and Degnan 2001, Johnson et al. 2005, Mariani et al. 2005, Kouchi et al. 2006). However, such models are usually more complex and difficult to implement, more demanding of computer time and tend to be species-specific. This undermines their benefits and limits their applicability in certain studies, especially when simulating over long periods of time. An initial analysis of the current data used in the present study showed that surface currents in the study region were generally the strongest throughout the model domain (Appendix D.1), and thus generate the longest advection distances and widest interconnectivity patterns. Therefore, in order to maximise long distance dispersal events and coastal connections (i.e., model worst-case dispersal scenarios), and make the model more general and reduce its complexity, only currents from the surface layer of the model were used to advect particles; effectively turning the 3D model into a two-dimensional (2D) model (i.e., limited to the horizontal component).

The model was forced using 13 years (1 February 1993 to 1 December 2006) of hourly meteorological data (i.e., wind, temperature, rainfall and solar radiation) from weather stations (operated by New Zealand MetService) at two locations (Figs. 5.1 and 5.2). A two–second time step was used to solve the hydrodynamic equations. The model generated hourly horizontal cell current and TKE fields for the same period of time, which were used to produce an hourly 2D current velocity profile. The first 20 days were discarded to eliminate possible inaccuracies due to spin-up artifacts of the model (Nehrkorn et al. 2010, Covey et al. 2011).

5.2.2 Advection-Diffusion model

Particle tracking models, also called dispersion models, simulate two different motions: 1) advective motion, and 2) turbulent motion. Advective motion, or advection, is the direct displacement of particles by currents, and is relatively simple to describe and implement through the same deterministic hydrodynamic solution (i.e., it is represented by the current field). On the other hand, turbulent motion represents the diffusion or dispersion component of the total motion (i.e., random motion generated by turbulence), for which quantification is challenging (Gargett 1985, Denman and Gargett 1995). In order to overcome this, most studies couple a random walk component into the Lagrangian particle tracking model (e.g., Visser 1997, Nahas et al. 2003, Marinone et al. 2007). By adding a random displacement to the simulated advection, the random walk component simulates and incorporates diffusion and dispersion into the model (Salamon et al. 2006).

The concept of particle eddy encounters has been successfully used to generate the random walk component (Ohba et al. 1997). For this, some authors have correlated the turbulent component to the advection TKE, and incorporated it into the equations of dispersion (e.g., Shuen et al. 1983, Oliveira et al. 2002). As the hydrodynamic model used in the present study is able to calculate and advect the TKE of the flow, the particle tracking advection-diffusion model used here has incorporated TKE using the same approach. The model is represented by the following Lagrangian stochastic equation, which was solved using a time step of one hour:

$$\frac{d\vec{X}_i}{dt} = \vec{U}_i(\vec{X}_i, t) + \vec{u}_i'(\vec{X}_i, t) \qquad \text{Equation 5-1}$$

where $\vec{X}$ is the space location and *i* is associated with each coordinate direction, t is time, $\vec{U}_i(\vec{X}_i,t)$ is the current velocity at $(\vec{X}_i, t)$ and $\vec{u}_i'(\vec{X}_i,t)$ is the fluctuating velocity at $(\vec{X}_i, t)$. This last term is the turbulent (i.e., stochastic or random walk) component of the model. By assuming isotropic turbulence, turbulent velocity components were obtained by randomly sampling a Gaussian distribution with standard deviation $\sqrt{2k/3}$, with k representing the TKE (Shuen et al. 1983, Jang and Acharya 1988, Oliveira et al. 2002, Guizien et al. 2006). Although solving the Lagrangian equation out of the hydrodynamic model (i.e., decouple modelling) is likely to introduce error, the computational advantage is that this approach increases the total number of possible simulations and runs (which is restricted by computational time), giving more statistically robust and representative results.

5.2.3 Particle movement

Propagules were represented by positively buoyant particles with a preset life span. For each hourly time step, horizontal current and TKE values at each particle location were estimated by linear interpolation. These values were then used in equation 5.1 to update the location of each particle individually. If the updated location was on land, the particle was returned to its previous position (Ådlandsvik et al. 2004, Condie et al. 2005). This process was repeated for each particle until it either completed its specified PPD (see below) or left the model domain. If the particle left the model domain, it was regarded as ‘lost’ and not considered in subsequent runs. However, its previous location was recorded to be included in the analysis of dispersion (Stephens et al. 2006).

5.2.4 Sub-regions, planktonic propagule duration and simulations

A total of 11 release points located throughout the study region were used for the simulations (Fig. 5.1). Each release point represented a coastal sub-region based on the anthropogenic pathway recreational boating (Chapter 3). In the present study each sub-region included a 2.5 km offshore buffer that reflected the spatial resolution of the hydrodynamic model, and also was inclusive of most of the marine structures visited by vessels (e.g., marinas, wharves), which are likely points for NIS introduction or reservoirs for their further spread (e.g., Bax et al. 2003, Glasby et al. 2007, Floerl et al. 2009). The specific location of each release point was determined as the location of the busiest pathway hubs and most used marine structures in each sub-region (Fig. 5.1).

PPD can vary greatly throughout the geographical range of each species, and as a response to environmental variables, such as temperature, salinity, and food quantity and quality (Eckman 1996). The simulations in the present study used PPDs of 1, 15, 30 and 60 days, which encompass a range of reported values of larval duration in the water column for well-recognised marine pest species, namely the clubbed tunicate *Styela clava*, the Mediterranean fanworm *Sabella spallanzanii*, Northern Pacific seastar *Asterias amurensis* and European shore crab *Carcinus maenas*, respectively (Table 5.1). In order to account for the effect of tides and possible synchronicity between release events and the tidal cycle (given by a tidal forcing period of 12.4 hours in New Zealand, Walters et al. 2001), particles were released every hour for a 24 hour period. A previous analysis using densities between 50 and 10000 per hourly release revealed that 100 particles adequately represented the stochastic component of the cluster and required significantly less computational time (Appendix D.2). Therefore, a group of 100 particles was released every hour for a 24 hour period (i.e., 2400 particles per simulation).

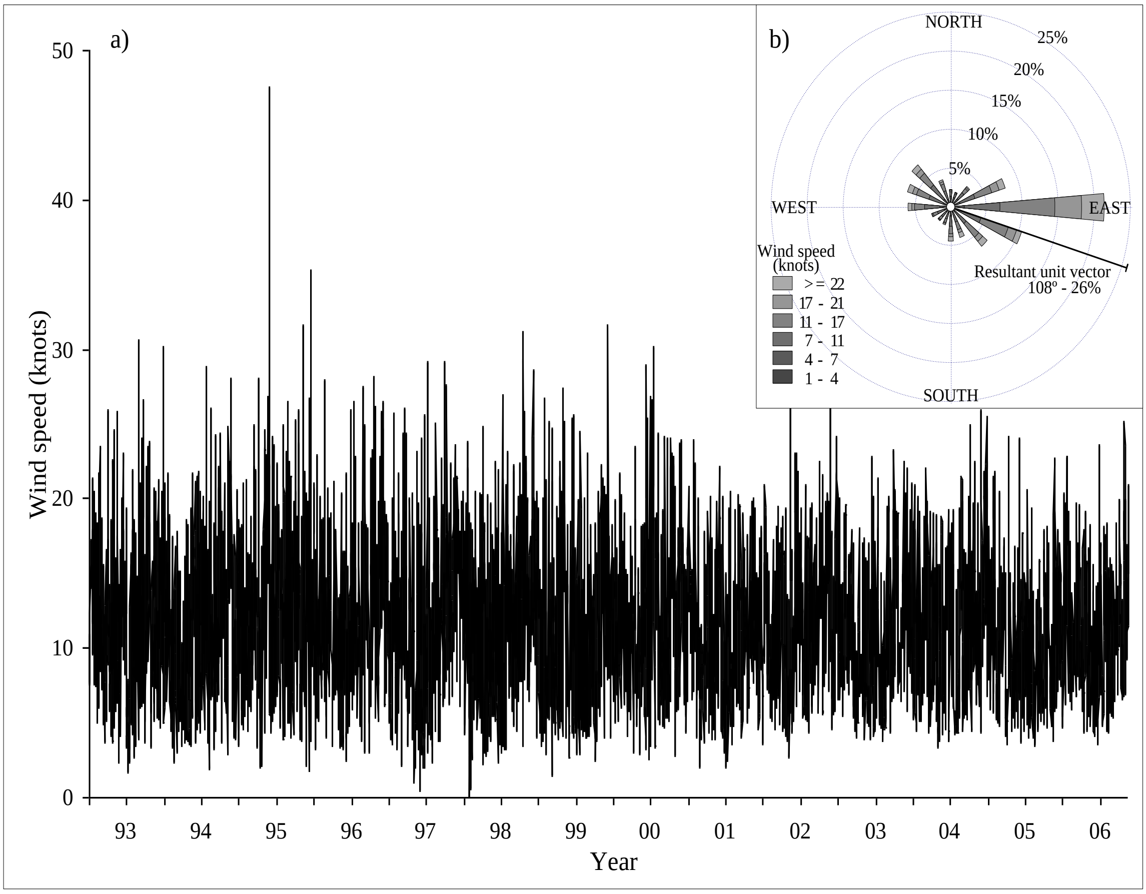

Figure 5.2 Wind information for the study region between 1 February 1993 and 1 December 2006. Data from weather stations at Farewell Spit and Stephens Island, operated by New Zealand MetService. a) Daily averaged wind speed (knots). b) Wind rose showing the predominant wind direction and resulting unit vector for the same period of simulations.

A simulation began with the release of the first cluster of 100 particles and finished when all particles of the 24 clusters released had completed their PPD. After this, a new simulation was initiated. Simulations were started at the beginning of the current field and repeated continuously throughout the entire data set for each PPD and release point, generating a run of simulations. By starting the first simulation (i.e., releasing the first cluster) a few days later (between 5–40) than the actual first day of the data set, additional runs were created for 15, 30 and 60 day PPDs. A total of 910, 936 and 789 simulations were generated for these PPDs, respectively. This made statistical analyses more robust and increased the release scenarios actually used (hence representing different environmental conditions) from those available in the hourly data set. As the 1 day PPD combined with an hourly release over 24 hours generated a run of 2474 simulations, which covered 97% of the potential release scenarios available in the data, no additional runs were considered for this PPD.

Table 5.1 Pelagic propagule duration (PPD). Reported PPD for four species currently under the New Zealand's unwanted marine organisms list. Pelagic propagule durations may vary through the geographical range of each species, and as a response to environmental variables, such as temperature and salinity, amongst others.

Species	Natural spread mechanism	Reported PPD	Reference
Clubbed tunicate (*Styela clava*)	Larvae	12–28 hours	Holmes 1968, Davis and Davis 2007
Mediterranean fanworm (*Sabella spallanzanii*)	Larvae	14 days	Giangrande et al. 2000
European shore crab (*Carcinus maenas*)	Larvae	21–50 days	Dawirs 1985, Mohamedeen and Hartnoll 1989
Northern Pacific seastar (*Asterias amurensis*)	Larvae	30–120 days	Paik et al. 2005

5.2.5 Advection and dispersion measures

In order to identify and characterise the dispersion pattern for each release point, as well as the effect of PPD on this pattern, two specific dispersion measures were used: 1) mean advection (MAD), and 2) dispersion cluster spread (DCS). The first parameter provided information on the distance that particles were dispersed from the release point, while the second parameter represented how closely the particles clustered after dispersion (i.e., how distant particles were from each other).

MAD was calculated as the mean of the distances between the release point (source) and the final position of the particles of a simulation (Fig. 5.3). DCS was calculated in the following three consecutive steps. First, the mean final position of the particles in the simulation was calculated. Second, the distance from the final position of each particle to this mean final position was obtained. Finally, the 90th percentile of these distances was calculated (Fig. 5.3). This value was arbitrarily selected, and graphically, it could be represented as the circle with its centre in the mean final position and of such a size that it encompasses 90% of the particles concentrated around its centre (Fig. 5.3). In this sense, a larger circle would represent a more spread dispersion cluster.

5.2.6 Connectivity measures

Connectivity was defined as the linkage among sub-regions, and determined by the probability of particle dispersion from one sub-region to another by water currents. In order to estimate the connectivity of links and sub-regions two values were defined: 1) Connectivity value (CV), and 2) Connectivity ranking value (CR). The CV represented the probability of NIS propagule spread between two sub-regions along their direct link or connection. It was defined as in other studies (e.g., James et al. 2002, Cowen et al. 2006) as the sum of all the particles (of all simulations) that, after release from one sub-region (source) were located within the other sub-region (recipient) at the end of their PPD, divided by the total number of particles released.

Using this approach, a CV was calculated for each of the 121 potential links (i.e., 11 sub-regions x 11 sub-regions, including 11 self-connections). When the source and recipient sub-region was the same (i.e., self-connection), the CV represented the retention value of that region (i.e., the probability that particles were within the boundaries of the source sub-region at the end of their PPD). CVs were used to generate a connectivity matrix for each PPD. By identifying how many sub-regions were inter-linked and how strong these links were, the connectivity matrix facilitated the visualisation of the connectivity and retention values of sub-regions within the network, as well as the variation in CV among sub-regions as a function of PPD.

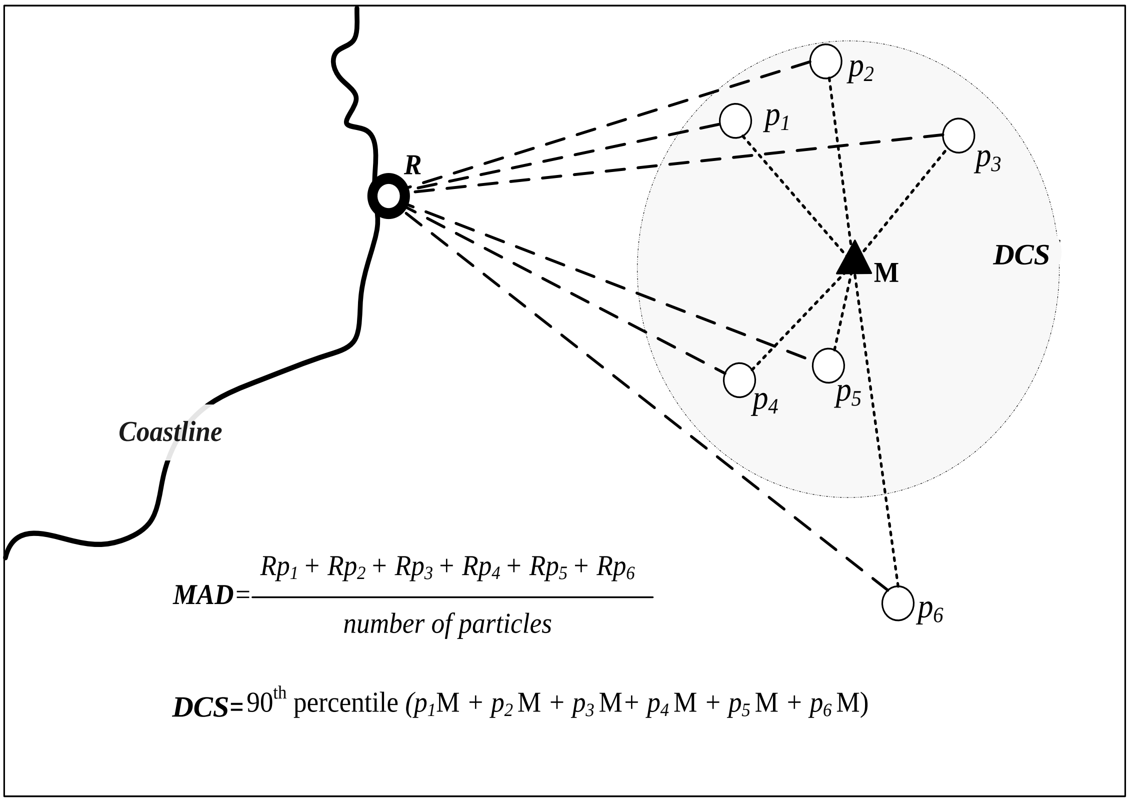

Figure 5.3 Mean advection distance (MAD) and dispersion cluster spread (DCS) calculation procedure. R= particles' release point, pi= particle position, M= mean final location of particles. In this example the total number of particles= 6.

CR is the new measure presented in Chapter 3 that provides an estimate of how 'well-connected' a sub-region is within the network (i.e., its connectiveness). It was defined here on the assumption that both the number of connections and the CV of each connection (i.e., the efficiency of the link) have an important effect on sub-region connectivity. The efficiency of a connection was determined by its CV, normalised by the total number of particles that would be transported along that connection under an 'ideal' dispersion scenario. The ideal scenario, in this case, was defined by two assumptions: 1) there was no particle retention, and

2) all connections were equally efficient, hence transported the same number of particles. The CR for a sub-region acting as a source was therefore represented as follows:

$$CR_i = (\sum_{j=1}^{j=m} \frac{CV_{i \to j}}{\phi_j}) * \frac{l}{p}$$ Equation 5-2

where subscript *i* defines the source sub-region, subscript *j* the recipient sub-region and *m* represents the total number of sub-regions considered. $CV_{i \to j}$ is the connectivity value between sub-regions *i* and *j*, and ϕ_j represents the total expected number of particles received by sub-region *j* from sub-region *i* under an ideal spread scenario. The variable *l* in the equation refers to the actual total number of connections (links), while *p* refers to the total number of potential connections. In this particular case, ϕ_j was a constant of 240 for all the connections (i.e., 2400 (total larvae released) **/** 10 (possible links)), and *m* and *p* had also a constant value of 10 for all sub-regions (i.e., self-connections were not considered). CR was similarly calculated for each region when acting as a recipient area.

5.3 RESULTS

5.3.1 Surface currents, advection and dispersion

Mean surface current velocities over the 13 year period ranged from 0.001 to 18.2 cm/s, with relatively strong currents evident in the vicinity of coastal sub-regions A (northern Golden Bay), H (eastern Tasman Bay) and J (French Pass) (Figs. 1.2 and 5.4). Similarly, surface currents showed a general easterly direction, consistent with the predominance of westerly winds during the simulation period (Figs. 5.2, 5.4).

Accordingly, advection (MAD), cluster spread (DCS) and particle loss varied greatly across sub-regions and in relation to PPD. Longer PPDs always generated greater values for MAD, DCS and particle loss (Fig. 5.5). There were significant correlations between dispersion measures (Spearman's rho 0.346–0.645, $p < 0.05$), with higher DCS values usually associated with longer MAD. There were no particles lost from the model domain for the 1 day PPD, but longer PPDs generated a significant increment in this parameter. As expected, particle loss in central sub-regions in the southern area of Tasman Bay (e.g., sub-regions F and G) was relatively low, while loss in sub-regions closer to the edges of the model domain represented by Golden Bay (i.e., sub-regions A and B) and French Pass and D'Urville Island (i.e., sub-regions J and K) was consistently the greatest (Fig. 5.5c).

MAD and DCS values were typically low for 1 day PPD and were similar across sub-regions. Conversely, although a similar general pattern was observed for MAD values for 15, 30 and 60 day PPDs, these values differed greatly across sub-regions. MAD values in sub-region A were greater than other sub-regions (Fig. 5.5a), consistent with its relatively strong mean surface current velocities (Fig. 5.4). In contrast, central sub-regions F and G in the inner parts of Tasman Bay had relatively low values (Fig. 5.5). Sub-regions I and K had comparatively lower MAD values than their adjoining sub-regions where mean surface current velocities were greater. DCS results were similar to those for MAD in that they also revealed consistent patterns across sub-regions for PPDs of 15, 30 and 60 days. While sub-regions F, G and K always had the lowest values, DCS for sub-region I was consistently greater than its neighbours, and the highest of all sub-regions for a PPD of 60 days (Fig. 5.5).

There was considerable variation in MAD, DCS and particle loss values for all sub-regions, which is evident in Fig. 5.5 in the large overlap of the standard deviation lines. A finer scale analysis revealed that this variability is a function of a wide range in particle advection distances and dispersion trajectories that occur over relatively short time scales (Fig. 5.6).

The examples in Figure 5.6 depict particle trajectories for two randomly chosen times within each of three randomly chosen days for a 1 month period in the 13 year data set. Clearly, depending on hydrodynamic conditions at the time of release, individual particles may be retained within a sub-region or advected across the model domain, and may travel in opposing directions.

5.3.2 Connectivity and source/recipient sub-regions

As with dispersion measures, the number of connections and their connectivity values varied depending on PPD and coastal sub-region (Fig. 5.7). The total number of connections increased when the PPD increased. However, this increment was typically associated with a decrease in the connectivity values for each pairwise combination of sub-regions (Figs. 5.7 and 5.8). Similarly, retention values within each sub-region decrease with increasing PPD, evident from pairwise comparisons (Fig. 5.7) and at a broad level for mean retention values across all sub-regions (Fig. 5.8).

Retention values were typically higher than CVs in all the sub-regions for all PPDs, as evident in the highest values along the diagonals in Figure 5.7. The notable exceptions were retention values of sub-regions E and F for 15, 30 and 60 day PPDs, which were considerably lower than some of their CVs. Similarly, the retention value of sub-region D for a PPD of 15 days was lower than most of its CVs. However, retention values for this sub-region were greater than CVs for PPDs of 30 and 60 days.

By defining a CV threshold of ≥ 5% in Figure 5.7, it is clear that the most connected sub-regions tend to be those adjacent to the retention value (i.e., diagonal of each matrix), even when long PPDs are considered. This is evident in the connectivity patterns for sub-regions D, E, F, G and H. However, there also were exceptions in which close spatial proximity did not necessarily imply high connectivity, especially as longer PPDs increased the opportunity for advection of particles far from their release point. An interesting example emerged when sub-region B was considered as the source region. Sub-region B includes the Tarakohe wharf and marina (Chapter 1) and marine farming structures (Chapter 4) that could act as potential reservoirs for the natural dispersal of marine pests to adjacent sub-region C (The Abel Tasman National Park), which incorporates the Tonga Island Marine Reserve (Figs. 1.2 and 5.1). However, for all PPDs the connectivity was very low (≤ 0.6%) between these two sub-regions. Furthermore, for PPDs ≥ 15 days the greatest connectivity to a recipient area was with sub-region K on the opposite (eastern) side of the study region.

An interesting feature of some of these connections is their asymmetry, with stronger connectivity in pair wise comparisons of sub-regions evident in one direction more than the other. For example, in a comparison of sub-regions F and G for a PPD of 30 days (Fig. 5.7c), the connectivity is notably stronger (~37%) when F is considered the source sub-region and G the recipient than when source and recipient are vice versa (9%). Roles of sub-regions as sources or recipients for particles are further highlighted by examination of CR estimates. CR varied with the PPD considered, with highest values for both source and recipient sub-regions obtained with PPDs of 15 and 30 days (Fig. 5.9). Central sub-regions in inner Tasman Bay generally function as greater source and recipients than peripheral sub-regions. Asymmetry in this general pattern is nonetheless evident, with sub-regions E and F having the highest CR scores as sources, and more eastern G and H sub-regions having the highest scores as recipients. This is consistent with the west-east counter-clockwise direction in the mean surface current field (Fig. 5.4).

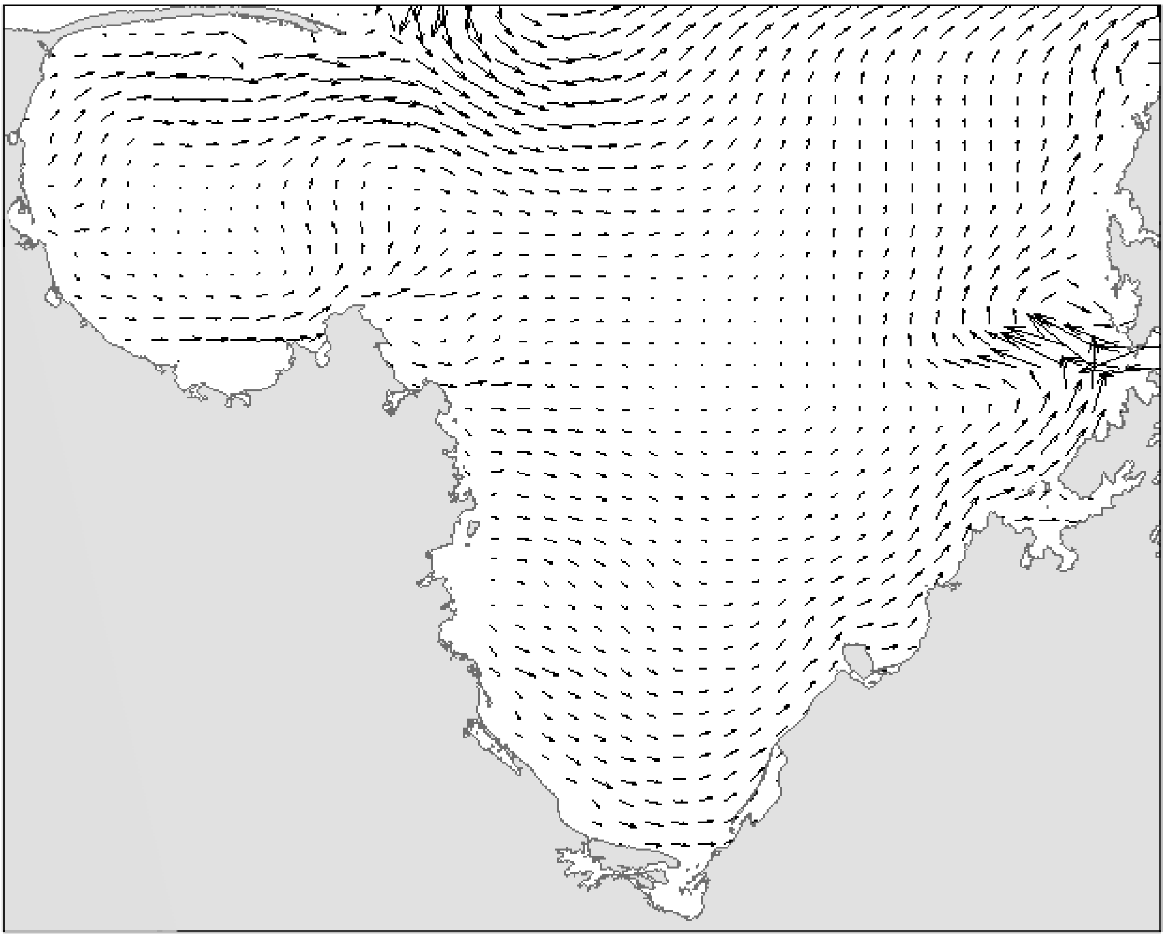

Figure 5.4 Mean horizontal current velocity field. Calculated as the mean of the 13-year hourly current velocity field for the study region. Time period: 1 February 1993 to 1 December 2006. Spatial resolution= 2.5 km2. Figure created using MATLAB™ v. 6.

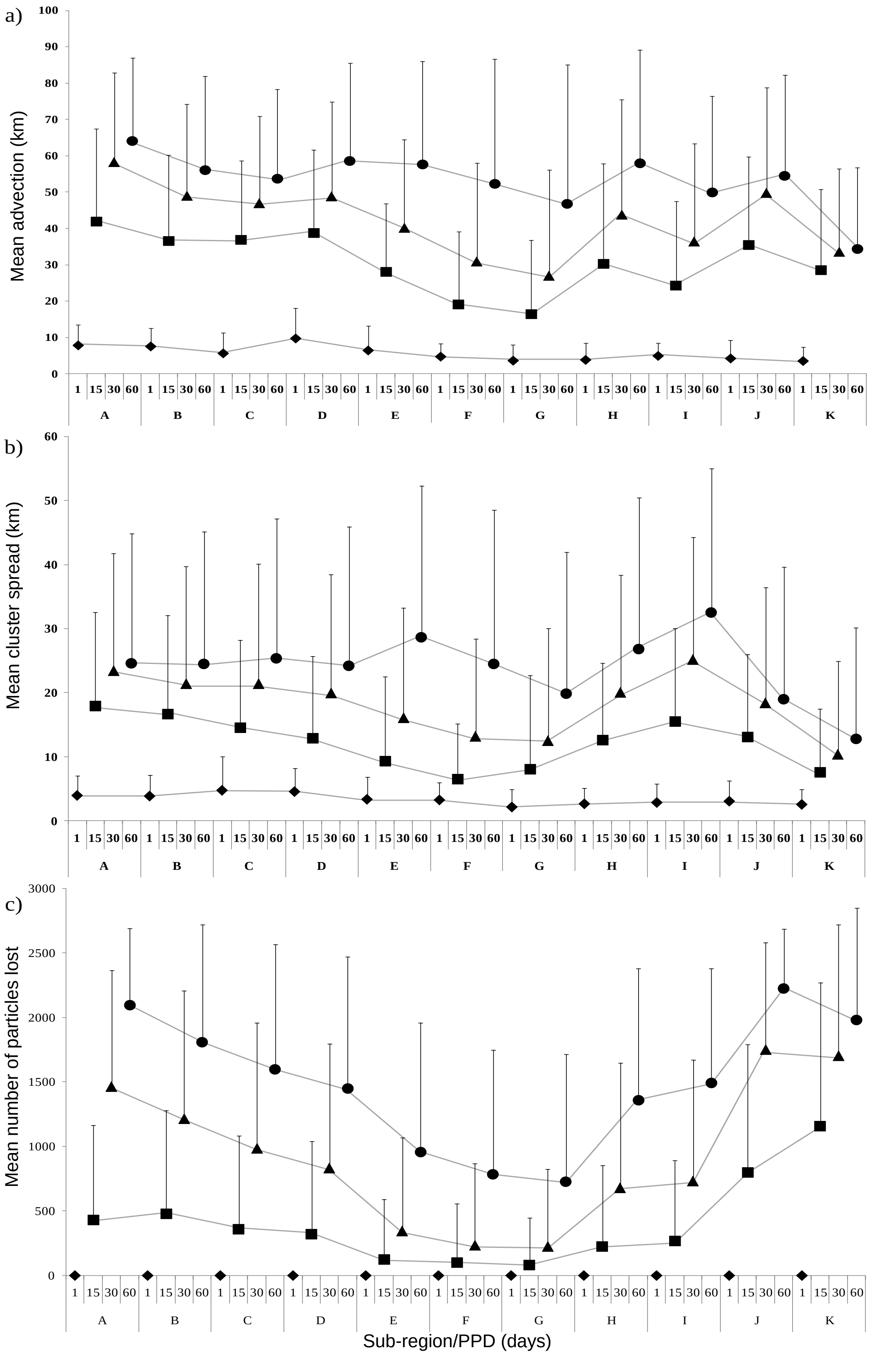

Figure 5.5 Mean dispersion measures (+ 1SD) for sub-regions A-K. a) mean advection, b) dispersion cluster spread (DCS), and c) mean propagule loss. Planktonic propagule duration (PPD)= 1 day (♦), 15 days (■), 30 days (▲) and 60 days (●).

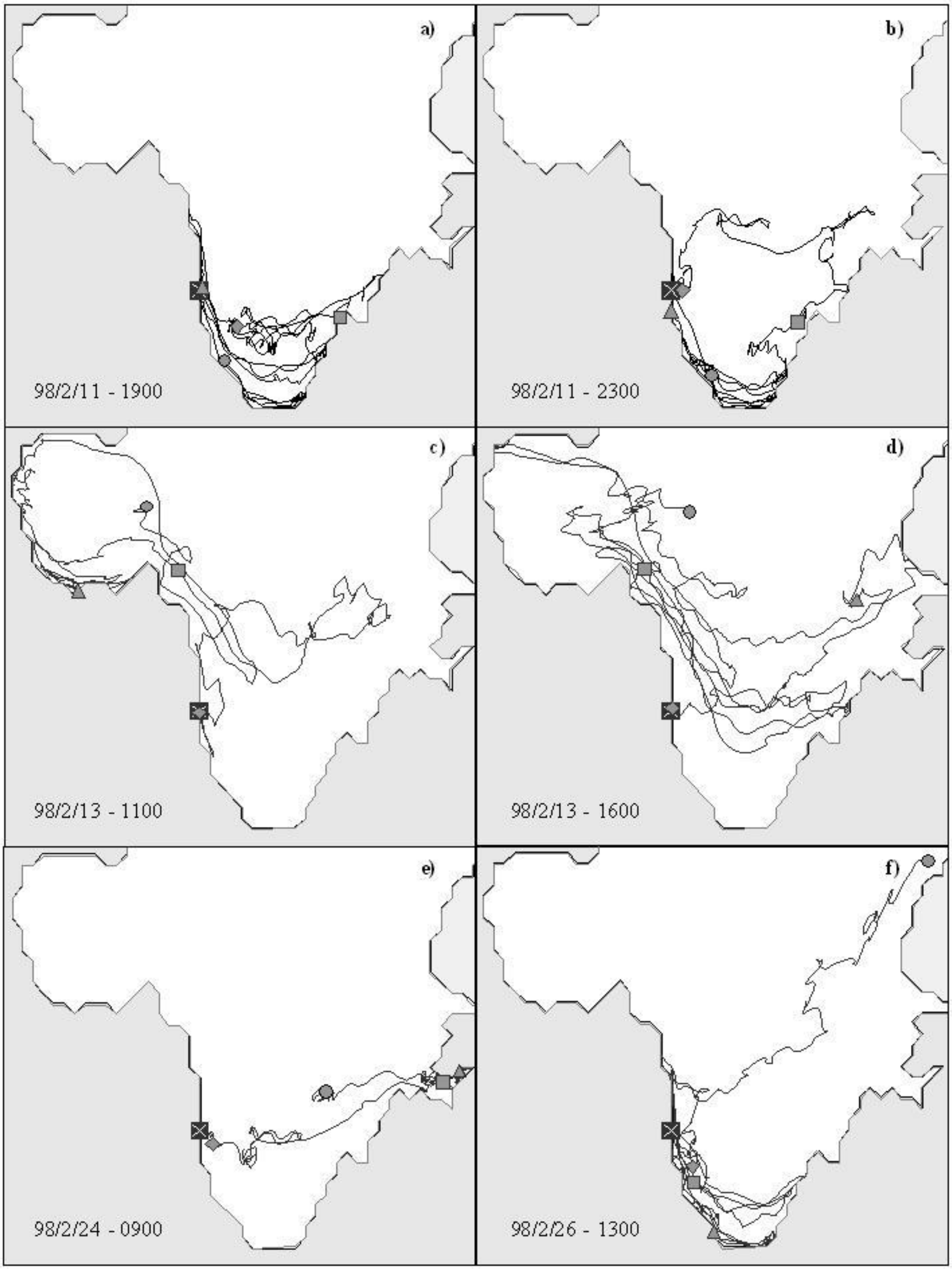

Figure 5.6 Dispersal trajectories of a single particle released from sub-region D. Current velocity field from February 1998**.** Sub-plots represent specific release times indicated at the bottom left of each graph (i.e., Year/Month/Day – Time). Release point (☒) and propagule location after 1 day (♦), 15 days (■), 30 days (▲) and 60 days (●)also are indicated in the graphs. Figure created using MATLAB™ v. 6.

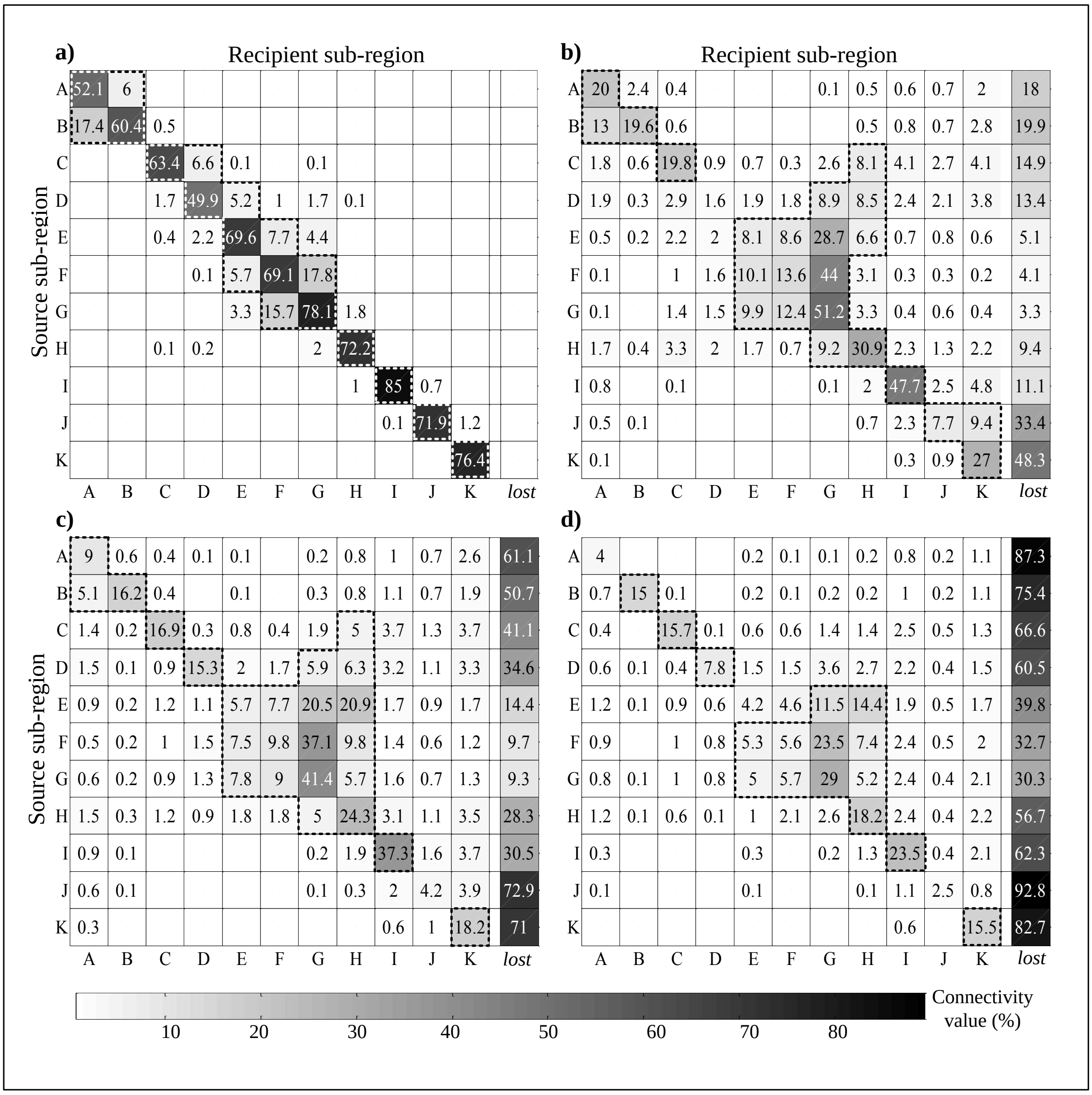

Figure 5.7 Connectivity matrices for sub-regions A-K for planktonic propagule durations (PPDs) of: a) 1 day, b) 15 days, c) 30 days and d) 60 days. Matrix cells indicate the connectivity value CV between source and recipient sub-regions (i.e., the probability of NIS propagule spread between the indicated source and recipient along their direct connection). Source sub-regions are represented in rows and recipient sub-regions in columns. If read from left to right, it is possible to identify how many recipient sub-regions are connected to a particular source sub-region and the strength (i.e., probability) of each connection. Similarly, if read from bottom to top, matrices shows how many source sub-regions are connected to a particular recipient sub-region and the strength of each connection. Matrix diagonals represent the retention value for each sub-region (i.e., the probability that particles were within the boundaries of the source sub-region at the end of their PPD). Empty cells indicate no connection between sub-regions (i.e., connection with probability= 0). Dashed lines represent connectivity values ≥ 5%. Column lost represents the probability of propagules leaving the model domain. Probabilities in the matrix do not sum to 100% as some propagules finish their PPD elsewhere within the study region.

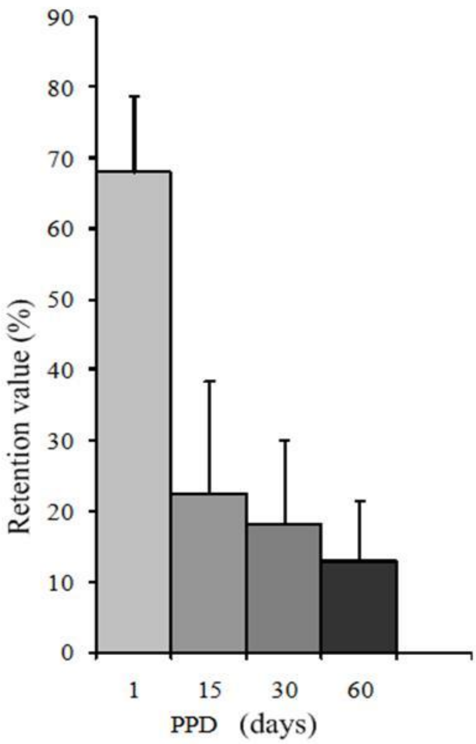

Figure 5.8 Mean retention values (+ 1SD) for planktonic propagule duration (PPD) of 1, 5, 30 and 60 days. Calculated as the mean of the retention value of all sub-regions.

5.4 DISCUSSION

5.4.1 Dispersion modelling approach

Advection-diffusion models can provide reliable results when evaluated over long periods, but on short timescales, their applicability might be limited due the substantial variability in the flow that characterises coastal circulation and the intrinsic variability of the dispersal process (Siegel et al. 2003). For example, simulating dispersal by coastal currents for a period not long enough to include a complete tidal cycle (e.g., < 12.25 hours in New Zealand) is likely to provide biased estimates of dispersal patterns. The present model used an hourly 13-years current velocity field, generated using real meteorological data and a validated hydrodynamic model, accounted for seasonal and inter-annual variation resulting from periodic phenomena (e.g., El Niño, La Niña), as well as sporadic extreme conditions that although rare (Fig. 5.2), are likely to affect propagule dispersal (Mearns 1988). Hence, much of the variability in the dispersion results could be attributed to real spatio-temporal differences in the advection and turbulent forces experienced by particles following their release.

Dispersal in marine environments is not only affected by hydrodynamic conditions, other factors, such as propagule pressure (i.e., number of propagules released and release frequency) and organisms' behaviour, also are important components of this process. The present study simulated hourly release events for a period of 24 hours (approximately 2 tidal cycles) throughout the data irrespective of the time of the year. However, in reality reproduction and propagule dispersal is often seasonal (especially in temperate marine systems), with highly species-specific propagule release strategies (e.g., Garcia 1992, Bobadilla and Santelices 2005, Saavedra and Pousão-Ferreira 2006) that may be synchronised with environmental variables, such as temperature (Moss 1998), light (West and Lambert 1976), salinity (Cook et al. 2005) and tidal cycles (Garcia 1992).

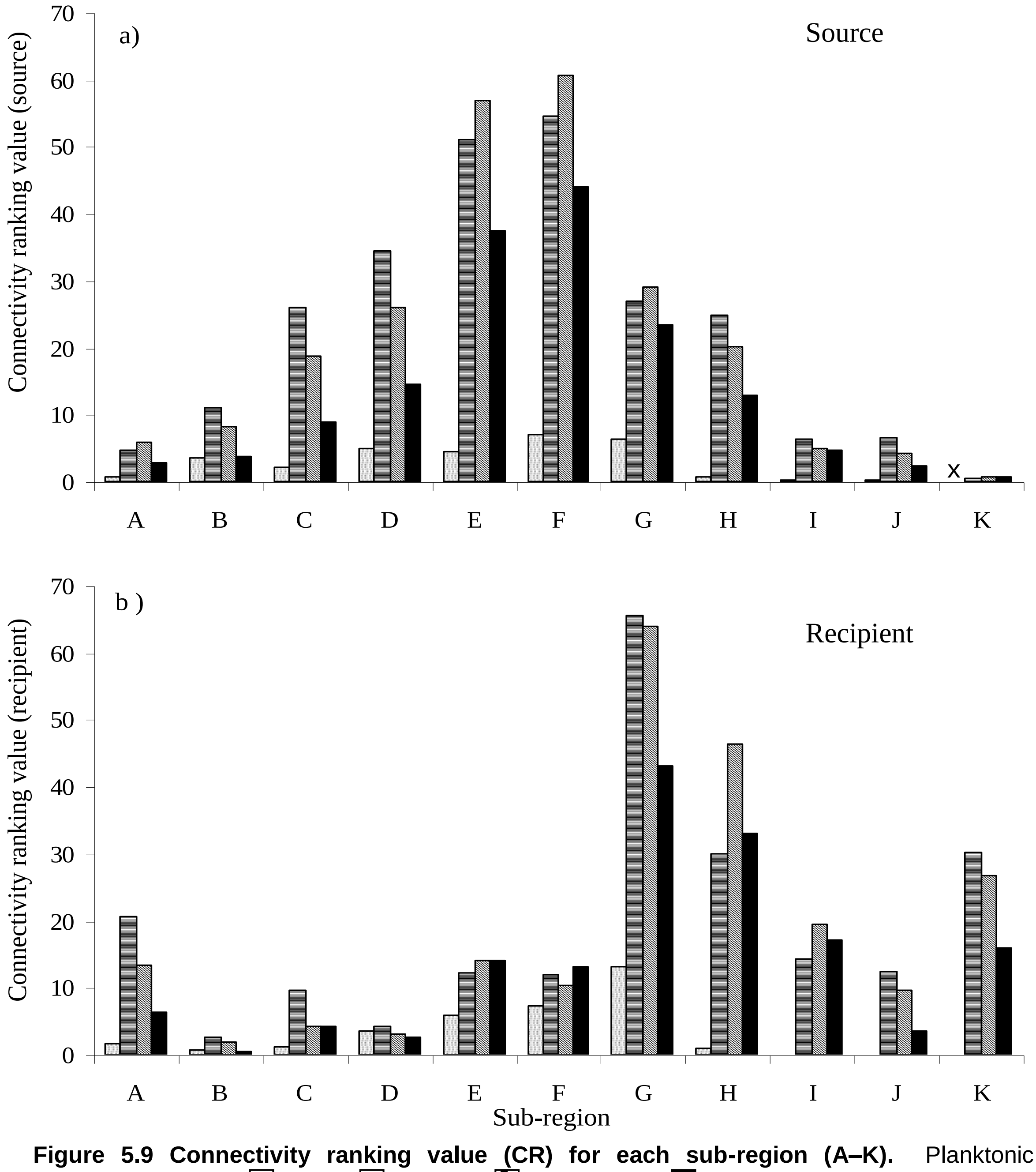

Figure 5.9 Connectivity ranking value (CR) for each sub-region (A–K). Planktonic propagule duration (1 day, 15 days, 30 days and 60 days) represented as mean values. a) Connectivity ranking values for sub-regions acting as sources. b) Connectivity ranking values for sub-regions acting as recipients.

Similarly, although the model used PPDs with a fixed length of time, true PPDs will vary considerably depending on a complex interaction of physical, chemical and biological variables (Pearse et al. 1991, Clarke 1992, Eckman 1996, Siegel et al. 2003). Furthermore, larval behaviour (swimming in particular) and mortality will also affect dispersal (Todd 1998, McQuaid and Phillips 2000). Hence, more realistic predictions of propagule dispersal in marine environments would need to consider species-specific spatio-temporal variation in the above factors. However, as the present objective was to reveal time-integrated patterns of dispersal and connectivity generated by surface currents across a range of PPDs, the application of a relatively simplistic particle dispersion model combined with a large data set and a small temporal scale was appropriate.

5.4.2 Dispersal and connectivity measures

Dispersal, defined as the movement of individuals (including propagules) among populations, is a critical ecological process (Ims and Yoccoz 1997). However, a range of (sometimes loosely applied) dispersal measures can be found throughout the literature, which makes comparisons amongst studies difficult. MAD (often referred as mean dispersal distance, or simply, dispersal distance), for example, has been widely used to investigate species dispersal potential in relation to local population dynamics (e.g., Pedersen et al. 2003, Peliz et al. 2007) and marine reserve modelling and management (e.g., Kaplan 2006). This parameter however, provides no information on the direction of dispersal or the spread of the particle cluster. Thus, it could not be used alone as an indicator of the potential fate of propagules. For this, additional parameters such as the angle of dispersion and the DCS value presented here are required.

Estimates of the dispersal angle (sometimes called direction), have been used in some dispersal studies (e.g., McQuaid and Phillips 2000, Nahas et al. 2003). Although the integration of a direction estimate into the analysis generates a more representative description of dispersal, the relevance of this parameter would be limited in cases where its values were highly variable. This, in addition to the conceptual and practical problems that arise when applying statistical concepts (e.g., mean, standard variation, mode) to angle metrics, would have challenged both the validity and accuracy of direction estimates in the present study. Therefore, no specific direction estimate was included in the analyses.

Conversely, by combining the variables MAD and DCS, the present study characterised dispersal patterns (also known as dispersal kernels) based not only on the magnitude of dispersal, but also on the density of the dispersed particles. Thus this approach improves the differentiation of dispersal patterns. In the present study, higher DCS values were usually associated with larger MAD values and longer PPDs. DCS also could be used to characterise and assess the dispersal potential of dioecious species (such as the invasive kelp *Undaria pinnatifida*), where proximity between male and female propagules would be a determining factor in population establishment (e.g., Arrontes 2005). In order to characterise the spread of particle clusters some authors have used the variance ellipse of the principal component analysis (e.g., Edwards et al. 2007) or the standard variation of the distance between the particles and their cluster centre of mass (Stephens et al. 2006). However, these parameters are more complex than the DCS presented here, and their application could be limited by the computer time required for their calculation.

Connectivity is a concept that has been applied in a wide range of fields, including larval dispersal and marine connectivity modelling (e.g., Wolanski et al. 1997, Condie et al. 2005, Marinone et al. 2007), metapopulation studies (e.g., Cowen et al. 2000, James et al. 2002, Becker et al. 2007), marine reserve networks (e.g., Laurel and Bradbury 2006, Mumby 2006) and ecosystem management (e.g., Roberts 1997). The basis for the calculation of connectivity is movement in a spatially structured environment (Moilanen and Hansky 2001), but different metrics are used in the literature (although Calabrese and Fagan 2004, provided a framework to decide which connectivity to calculate).

Unlike estimates based mainly on 'presence or absence' of connections, the connectivity value (i.e., CR) applied in the present study accounted for the efficiency of the links. Moreover, CR accounted not only for the total number of links and their efficiency, but also the theoretical spread potential of each sub-region in the network. In this way, it provides a more realistic parameter for comparing different areas in terms of their connectivity as both sources and recipients. For example, visually their connections with all the other sub-regions for PPDs ≥ 15days suggest that eastern sub-regions I and K are better recipients than the others (Fig. 5.7). However, when CR values are considered, sub-region G that has fewer connections is revealed as a better recipient (Fig. 5.9). It is important to note that depending on the analysis, CR can be modified to better represent the modelled scenario. Factors such as distance between connected regions or their conservation values for example, can be integrated into CR to provide a more meaningful estimate (Chapter 3).

5.4.3 Dispersal, connectivity and implications for NIS management

Connectivity in the study region was low for a 1 day PPD and limited primarily to adjacent sub-regions, with the number of connections increasing with increased PPD to a point where most sub-regions were interconnected. Hence, for species with a short PPD such as *S. clava*, dispersal by coastal currents is likely to be limited, and rely more on the human-mediated pathways present in the region (e.g., recreational boating, aquaculture). On the contrary, species with a longer PPD, such as *A. amurensis,* could be advected across the entire study region by the dispersal forces of surface currents alone.

These results imply that longer PPDs may lead to relatively rapid natural dispersal to an extent that undermines any efforts to manage human transport pathways between key sub-regions (e.g., between an infected vector hub and sub-region with important conservation values). However, specific evaluation of such risks would need to recognise that connections between sub-regions may be asymmetric, as in the study region where stronger connectivity in pair wise comparisons was evident in one direction more than the other. Moreover, the rate of a species spread will depend on whether it successfully establishes along its pathway of dispersal (Forrest et al. 2009).

Where habitat is not a limiting factor, a species with even short-range dispersal may spread relatively quickly through multiple cycles of planktonic dispersal, recruitment and subsequent larval release, thus negating the benefits from managing anthropogenic pathways. Conversely, in the case of a fouling organism with a short PPD, vast tracts of soft-sediment typical of many coastal environments (and evident across the study region) may act as a barrier to natural dispersal and establishment, hence an 'internal border' around which pest management efforts can be undertaken (Forrest et al. 2009).

The results demonstrate that surface currents have the potential to spread NIS with long PPDs across scales of tens of kilometres or greater. However, the final end-point for propagules shows considerable temporal variability. The marked variation in particle advection and trajectories across short time scales from the same release point (Fig. 5.6), clearly reveals that NIS dispersal patterns will be dictated by the hydrodynamic conditions at the time of release. This variation translates into uncertainty when attempting to define specific dispersal and connectivity patterns for management purposes. For example, this would be the case when considering episodic events such as the release of NIS propagules in ballast water discharge or biofouling during transit of a vessel into port. However, for strategic decisions relating to longer term management (e.g., is regional management of vessels and other vectors worthwhile?), the relatively long-term dispersal and connectivity patterns presented here have considerable utility in the design and implementation of regional NIS biosecurity programs.

5.4.4 Application of the model to management scenarios

The above points can be demonstrated using two specific invasion and management scenarios in the study region. The first example considers an initial incursion of a pest species in Port Nelson (sub-region G, Fig. 5.1) and its implications for the region's values. The second considers exacerbation of the secondary spread of NIS from infected areas to vector hubs.

Example 5.1: Dispersal of NIS from high risk points of entry to high value areas

Port Nelson is one of New Zealand's busiest fishing and shipping ports and a potential hot-spot for the arrival of NIS (Inglis et al. 2006a,b). Piola and Forrest (2009) recognised that if a marine pest was introduced to the Port area, other vectors would be likely to spread it to high value areas within the region, which include two Marine Protected Areas (i.e., in sub-regions C and H), New Zealand's largest estuary Waimea (sub-region F) and significant aquaculture zones (sub-regions A, B and D) (section 1.4). If the connectivity estimates between the Port (as the source) and these high value sub-regions (as recipients) are extracted from the matrices in Figure 5.7 for a range of indicative pest species (and PPD values), the differences in the susceptibility to invasion by natural dispersal are evident (Table 5.2).

The values in Table 5.2 indicate, for example, that in comparison with the more distant and less well connected (CV values ≤ 1%) aquaculture areas, the region's nationally significant estuary is susceptible to the natural dispersal of many pest species. Even organisms with a short PPD may spread directly by natural dispersal to the estuary and Marine Protected Area adjacent to the port. Conversely, natural spread to aquaculture areas (although theoretically possible) is very unlikely, even for NIS with lengthy PPDs (e.g., > 15 d). The frequent movement of recreational vessels (Chapter 3) and aquaculture vectors (Chapter 4) between the Port (sub-region G) and marine farming areas therefore, could play an important role in the spread of NIS. Hence, managing these human-mediated pathways may have some benefit (e.g., delayed timeframe to initial incursion, reduced rate of spread).

Table 5.2 Connectivity values (CVs) for a range of planktonic propagule durations (PPD). Connectivity values for PPDs of indicative NIS, between Port Nelson and other areas. Connectivity for Port Nelson as a propagule source, and the distribution of key aquaculture and conservation values across the study region (see sub-region locations in Fig. 5.1). CVs (indicated as percentages) were extracted from Figure 5.7 and rounded to the nearest whole number. Dashed line indicates zero connectivity.

Sub-region	Uses and Values	PPD ~1 d (e.g., *Styela clava*)	PPD ~15 d (e.g., *Sabella spalanzanii*)	(PPD ~ 30 d) (e.g., *Asterias amurensis*)
A	Mussel aquaculture	–	< 1	1
B	Mussel spat supply	–	–	< 1
C	Marine Protected Area	–	1	1
D	Mussel aquaculture	–	2	1
F	Nationally significant estuary	16	12	9
H	Marine Protected Area	2	3	6

Example 5.2: Secondary spread of NIS by dispersal from infected areas to vector hubs

CR values revealed that some sub-regions will function more as propagule sources than recipients, or vice versa. CR values for the system suggest that NIS incursions in central sub-regions E and F could have the greatest impact in the region because they are primary sources of propagules. Such areas should be targeted by NIS surveillance programmes. Furthermore, CR values showed sub-region G (the Port) as a likely end point for NIS propagules released from E and F, and other sub-regions. As sub-region G includes the largest marina in Golden and Tasman Bays and one of the nation's most important ports, cross-contamination between natural currents and human-mediated pathways (especially vessel related), could exacerbate the 'stepping stone' spread of NIS across the region and in fact, nationally. Together with Example 5.1, this second example highlights that sub-region G should be a priority for NIS management.

These examples also demonstrate how management of human-mediated pathways can be prioritised based on natural dispersal potential and connectivity. However, connectivity patterns should be used only to prioritise management and not as an argument to leave specific connections or human-mediated pathways unmanaged. The invasion process is associated with large uncertainty (Smith et al. 1999, Wonham et al. 2000). Hence, even with high CV values there is no assurance that NIS propagules will be advected into specific sub-regions and trigger an invasion. Ignoring management of human-mediated pathways will only increase the probability of transporting NIS between sub-regions. Also, by managing (i.e., preventing) translocations via human-mediated pathways it is possible to reduce NIS propagule pressure in recipient sub-regions, which may reduce the probability of NIS incursions being successful (Ruiz et al. 2000b, Verling et al. 2005).

5.5 CONCLUSIONS

This chapter demonstrates that advection-diffusion models applied over long time scales and integrated with dispersion and connectivity parameters (especially the DCS and CR presented here) can assist in the understanding of marine dispersal and invasion processes at regional scales, thus help to advise management priorities. The high variability observed in dispersion and connectivity values associated with location, PPD, and time period demonstrates that the fate of propagules will be species and spatio-temporally dependent. This highlights that the general connectivity patterns described here could be used to prioritise management, but it would be unrealistic to base decisions only on model outputs. The model could still be used as a baseline for the development of more complex scenarios, where the inclusion of additional variables (e.g., larval behaviour, mortality) to simulate specific species and situations, would generate more accurate dispersion and connectivity patterns. Further refinement of the approach to also include estimates of post-dispersal establishment potential, human-mediated pathways of spread, and the ecological and other values at risk, would greatly assist in the formulation of NIS management strategies

Chapter 6: Synthesis and future directions

This chapter provides a brief summary of the information and concepts presented, generated and discussed in this thesis, followed by an integral analysis of the non-indigenous species (NIS) pathways recreational boating, aquaculture, and natural currents, in the Golden Bay and Tasman Bay region. Potential management implications and opportunities resulting from the analysis are also discussed. Finally, recommendations for future applications and possible improvements to these concepts developed are discussed.

6.1 SUMMARY OF INFORMATION

Marine invasions are the result of intricate processes that can occur at different spatial and temporal scales and via a range of human-mediated and natural pathways. As with terrestrial and freshwater counterparts, invasions in the marine environment are a four-step process: 1) NIS entrainment by a vector, 2) NIS transport between environments, 3) NIS release from the vector, and 4) establishment of a viable population (Lockwood et al. 2005). The occurrence and success of each of these steps depend on inter actions among species-, pathway- and environment-specific variables (Carlton 1996, Lonsdale 1999).

Each step, and thus the entire process, is subject to high levels of stochasticity (Williamson 1996, Heger and Trepl 2001). Even when only one pathway (e.g., aquaculture (Chapter 3)), or just one part of the process is analysed (e.g., release of NIS into the new environment from a vessel (Chapter 2)), the invasion process reveals a great level of complexity (Hayes 2002b, Acosta and Forrest 2009, Chapter 2).

6.1.1 Conceptual models, a good start for invasion management

The value of risk assessment frameworks for identifying effective marine NIS preventative and control options, and thus basis for management strategies, has been increasingly recognised (Hayes 1997, Hewitt and Hayes 2002, Forrest et al. 2006). Effective risk assessments are however contingent on having decent conceptual models as a starting point (Burgman 2005). NIS management actions and policies would benefit significantly from a good conceptual model as a starting model, particularly in areas where available data are limited (e.g., Hayes 1998, 2002b, Landis 2003, Chapter 2).

Conceptual models assist analysts to identify essential components of the process/system considered, and to define appropriate assessment and management options. This is clearly demonstrated by the models developed for the recreational boating (Chapters 2 and 3), and aquaculture (Chapter 5) pathways. The former, for example, makes it evident that in addition to hull fouling (including niche areas), other vessel components and mechanisms (e.g., sediment retained on the deck) may be important in the spread of NIS via recreational vessels. Although seemingly obvious and trivial, this is a significant finding, as to date, most research and management of this pathway has been focused on hull fouling alone (e.g., Ashton et al. 2006a, Floerl et al. 2005a, 2009, 2010a, Bell et al. 2011, MAF2011c). Similarly, the recreational boating model recognises the key role of pathway stakeholders (i.e., vessel operators) in NIS spread events as well as in the success of preventative and control actions (Chapter 2). Hence, pathway stakeholders can be considered an assessment and management priority for biosecurity programmes (Piola and Forrest 2009).

The aquaculture model reveals that in Golden Bay and Tasman Bay this pathway encompasses more processes than just spat collecting, seeding, harvesting and crop transport to processing plants (Chapter 4). Components such as hatcheries and spat cleaning facilities can be readily identified in this model as potential sources of incursions, or points for cross-contamination where management may be desirable (Fig. 4.2). The model also highlights interactions with other pathways such as research and public aquaria that considerably increase the complexity of the aquaculture network and its spatial range in this region (Chapter 5).

6.1.2 Expert opinion and fuzzy logic, useful in biology of invasion

Risk assessments of marine invasions are highly dependent on expert opinion (e.g., Hayes 2002a, Minchin et al. 2006b, Gust et al. 2008, Campbell 2008, Campbell and Hewitt 2008, Inglis et al. 2012b). Analysts should ensure however, that before using expert opinion as a data source and support for decision-making processes, its associated uncertainty is minimised (Moon and Kang 1999, Burgman 2005). Ambiguity (Regan et al. 2002, Burgman 2005), definitional disagreements (Clemen and Winkler 1999) and underspecificity (Morgan and Henrion 1990, Regan et al. 2002) are important uncertainty sources in expert opinion. When more than one expert is used, different knowledge levels among experts (Ayyub 2001), lack of agreement on the way the analysed systems function and expert correlation brings substantial uncertainty (Burgman 2005). However, by considering the above factors when selecting the methodology (e.g., Delphi method) and designing the elicitation exercises, expert opinion uncertainty can be reduced (e.g., Chapter 2, Chapter 3 and Chapter 4).

Expert data integration can be theoretically and practically challenging. Several approaches such as weighted combination of probabilities, Bayesian combinations, and psychological scaling have been to date proposed (Cooke 1991). Fuzzy logic (Zadeh 1965) techniques are however, increasingly accepted as a well suited approach for expert opinion averaging (e.g., Moon and Kang 1999, Cheung et al. 2005, Prato 2007, Mouton et al. 2009, Mendel and Wu 2010, Chapter 3, Chapter 4).

Fuzzy logic is able to deal with the uncertainty caused by the vagueness of the language and thus, makes computing with words directly possible (Zadeh 1996). Interval type–2 fuzzy logic, a special type of fuzzy logic, can also model the uncertainty originated from people conceiving the same work differently (Mendel 2002). Some people, including experts, prefer expressing probabilities qualitatively rather than quantitatively (Morgan and Henrion 1990). Interval type–2 fuzzy logic therefore appears as an ideal approach to both elicit and integrate knowledge from experts (Mendel 2002, 2003, Acosta et al. 2010, Mendel and Wu 2010, Chapter 3, Chapter 4). Elicitation processes based on this methodology are more natural and straightforward, eliminating the need for expert education (e.g., Acosta et al. 2010, Chapter 3, Chapter 4). They also allow scientists, managers and stakeholders to communicate using the same risk ‘language’, increasing the likelihood of agreement among these groups.

6.1.3 Natural versus human-mediated spread

In contrast to human-mediated pathways, management of natural dispersal mechanisms in the marine environment is considerably limited, if not unrealistic. Hence, when both natural dispersal mechanisms and human mediated pathways co-exist, it is the likelihood of natural dispersal of NIS that would primarily determine what the efficacy, and thus value, of managing human-mediated pathways would be (Forest et al. 2009). An understanding of the dispersal and connectivity patterns created by natural dispersal within a region is therefore essential to define effective regional surveillance, response and control management strategies (Inglis et al. 2006d, Aquenal Rty Ltd. 2008a,b, Forrest et al. 2009, Chapter 6).

Particle dispersion models are useful to assess natural dispersal of organisms in marine environments (e.g., McQuaid and Phillips 2000, Shanks et al. 2003, Brickman and Smith 2007, Chapter 6). Dispersal and connectivity patterns based on these models are however, highly dependent on the hydrodynamic and biological variables used in the simulations. Models applied over longer periods (e.g., 13-year hourly data (Chapter 6)) are more likely to generate reliable results because long term modelling will average out the large variability in both the hydrodynamic flow patterns in coastal circulation systems as well as intrinsic variability of dispersal processes (Siegel et al. 2003).

6.1.4 Biological invasions, a connectivity issue

Biological invasions can be perceived as an issue of connectivity. Two regions could not infect each other unless they are connected naturally or by human activity. In fact, the dramatic increase in the number and rate of biological invasions throughout the world is believed to be mainly the result of increased connectivity (Carlton 1989, Levine and D’Antonio 2003, Crooks and Suarez 2006, Pysek et al. 2010,). The connectivity of a region determines its likelihood of 1) receiving an NIS (recipient region) and 2) providing NIS for other regions (source region). Hence, understanding NIS spatial connectivity is integral to biological invasions research and effective biosecurity strategies (e.g., National Research Council 2008, Glasby and Lobb 2008, Simkanin et al. 2009, Chapter 3, Chapter 4, Chapter 5).

Connectivity estimates can be valuable to assist with prioritising NIS research, surveillance and control activities (Chapter 4, Chapter 6, Stasko 2012). Most connectivity estimates only consider the number of connections not the efficiency of such connections when evaluating connectivity (e.g., James et al. 2002, Laurel and Bradbury 2006). The Connectivity ranking value (CR), presented in Chapter 3 and Chapter 5, in contrast, integrates not only these two variables (number and efficiency), but also the theoretical connectivity potential of the region analysed. Hence, CR appears to be a more realistic and objective parameter for comparing connectivity and prioritising management among regions. Similarly, CR could be modified to accommodate other parameters of the connections and regions (e.g., distance, pollution level, endemism), which widens its potential range of applications (e.g., ecotoxicology, metapopulation biology).

6.1.5 NIS management prioritisation

Management prioritisation is likely to improve the efficiency of biosecurity programmes, especially under (usually common) scenarios of limited management resources. Prioritisation can be conducted across pathways, vectors, and regions at different spatial scales. Approaches such as fault tree analysis (e.g., Chapter 2), the CV (Chapter 3, Chapter 5), and the Priority ranking value (PRV, Chapter 3) can be applied to inform effective pathway management for biosecurity purposes.

6.2 INTEGRAL ASSESSMENT AND MANAGEMENT IMPLICATIONS

It has been emphasised throughout this thesis that managing NIS pathways individually in a region, where there is a range of potential spread mechanisms, is likely to be both impractical and unsuccessful. Even the effect of removing a pathway, considered the only approach that ensures complete prevention of NIS introductions via a pathway mechanism (Carlton and Ruiz 2005), could be considerably reduced, or even annulled, by the presence of other unmanaged pathways. Effective management strategies should be based on integral assessments across all regional NIS pathways (Aquenal Rty Ltd. 2008a,b, Glasby and Lobb 2008, Forrest et al. 2009, Chapter 4, Chapter 5). This would also allow prioritisation of pathways and thus, improve such strategies.

The importance of integral assessment of NIS pathways can be demonstrated by analysing the overall connectivity created by: 1) recreational boating (Chapter 3), 2) aquaculture (Chapter 4), and 3) natural currents (Chapter 5) within Golden Bay and Tasman Bay. The matrix presented in Table 6.1 analyses the connectivity of these pathways, which here is defined simply as the presence/absence of a particular pathway between the 11 coastal sub-regions discussed in Chapter 3 and Chapter 5. Each sub-region could then be connected by a pathway (or combination of pathways) to the other ten sub-regions.

Connectivity patterns in the study region varied between moored and trailered vessels (Chapter 3). They also varied across the pelagic propagule duration (PPD) range considered (Chapter 5). However, in order to simplify the analysis, the matrix did not consider connectivity differences between recreational vessel types or across PPDs. In this sense, two sub-regions were considered connected via recreational boating if either vessel type linked them (Chapter 3, Table 6.1). Similarly, sub-regions were considered connected via natural currents if any of the PPDs (i.e., 1, 15, 30 or 60 days) produced a connectivity >5% between them (Chapter 5, Table 6.1). In contrast to the connections created by natural currents, all the connections created by recreational boating and aquaculture movements were assumed bidirectional.

Despite its simplicity, this integral assessment reveals a general connectivity pattern with important biosecurity management implications for Golden Bay and Tasman Bay. When all these three pathways (recreational boating, aquaculture and natural currents) are considered, 76.4% (84 links) of the total theoretical connectivity (10 links per region, 110 total links) is achieved (Table 6.1). Therefore, although the likelihood of entrainment from, transport to, and arrival into a sub-region of a NIS would be species- and vector-specific (Carlton 1996, Rouget and Richardson 2003), the Golden Bay and Tasman Bay region could be considered as an 'efficient' network for the spread of NIS. Similarly, five sub-regions (sub-regions C, E, G and K) are linked to each other and all the other sub-regions: each is able to directly interconnect the entire study area by itself. Such connectivity implies that, under a NIS spread scenario, these sub-regions would be more 'efficient' both as source and recipient areas than the other sub-regions. Hence, marine biosecurity programmes in the area should prioritise sub-regions such as these that are highly connected.

Even though the study region does not show 100% direct connectivity (where all sub-regions connected to each other), all sub-regions appeared to be interconnected when considering indirect connectivity. For example, sub-region F is not directly linked to sub-regions A or B, but sub-region C is connected to all three (Table 6.1). Sub-region C is then indirectly connecting sub-region F to sub-regions A and B. Although the probability of NIS translocation between sub-regions via indirect connections could be (intuitively) considered lower than via direct connections, the indirect connectivity is still likely to increase the potential for NIS spread within the entire region, than if no connectivity existed at all.

Similarly, absence of natural spread between specific coastal sub-regions should encourage management of recreational boating and aquaculture vectors between such sub-regions. It should also encourage emergency eradication responses (e.g., Coutts and Forrest 2007, Hopkins et al. 2011, Jones et al. 2012). For example, managing the overall movement of these vectors between Golden Bay (sub-regions A and B) and Tasman Bay (sub-regions C–K) may delay the initial incursion and/or reduce spread rate, if not prevent the spread of NIS between the two bays. In contrast, managing human-mediated vectors between sub-regions where NIS could be transported by coastal currents (such as in sub-regions A and B, and within sub-regions E, F and G (south-west of Tasman Bay)) appears unwarranted, as the natural pathway has the potential to undermine the management of human-mediated movements (Table 6.1).

As a third point, in all sub-regions except C, J and H, there is pathway overlapping between recreational boating and aquaculture, which creates cross–contamination opportunities. These would be of key importance in shared facilities such as marinas, boat ramps and mooring areas (Chapter 4). Fourthly, having the widest spatial range, recreational boating should be a management priority. Moreover, this pathway seems to be the only spread mechanism for the Abel Tasman National Park (sub-region C). Managing recreational boating could therefore protect the range of highly-valued resources (e.g., conservation, socio-economic) encompassed by the Park (Chapters 1). It could also considerably reduce the likelihood of spread NIS within the region.

Additionally, arguing a likely spread of NIS via other mechanisms, including natural currents, some aquaculture stakeholders in the region have been reluctant to implement vector management, even when facing incursions of recognised aquaculture pests such as *Didemnum vexillum* and *Styela clava* (e.g., Coutts and Forrest 2007). However, the connectivity matrix clearly shows that under such an invasion scenario, aquaculture would be the most likely (if not the only) pathway for the spread between Golden Bay (sub-regions A and B), Croisilles Harbour (sub-region I) and D'Urville Island (sub-region K) (Table 6.1).

Table 6.1 Integral connectivity assessment within Golden Bay and Tasman Bay. Connectivity of coastal sub-regions created by the recreational boating (RB), aquaculture (AQ) and natural currents (NC). **TP**= Total regions connected per pathway. **TAP**= Total regions connected by all pathways.

Source sub-region \ Recipient sub-region	A	B	C	D	E	F	G	H	I	J	K	TP	TAP
A		RB AQ NC	RB	AQ	AQ		RB		AQ		AQ	3 5 1	7
B	RB AQ NC		RB	AQ	AQ		RB		RB AQ		RB AQ	5 5 1	7
C	RB	RB		RB NC	RB	RB	RB	NC	RB	RB	RB	9 - 2	10
D	AQ	AQ	RB		RB AQ NC		RB AQ NC	NC	AQ		AQ	3 6 3	8
E	AQ	AQ	RB	RB AQ		RB AQ NC	RB AQ NC	NC	RB AQ	RB	RB	7 6 3	10
F			RB		RB AQ NC		RB NC	NC			RB	4 1 3	4
G	RB	RB	RB	RB AQ	RB AQ NC	RB NC		RB NC	RB	RB	RB	10 2 3	10
H							RB NC		RB	RB	RB	4 - 1	4
I	AQ	RB AQ	RB	AQ	RB AQ		RB	RB		RB	RB AQ	7 5 -	9
J			RB		RB		RB	RB	RB		RB NC	6 - 1	6
K	AQ	RB AQ	RB	AQ	RB	RB	RB	RB	RB AQ	RB		8 4 -	10

Another thing to consider is that stakeholders of specific pathways (e.g., recreational boating, aquaculture) are more likely to implement management when it is applied equally across all pathways (Sinner et al. 2000, Forrest and Blakemore 2002). It is, however, conceivable that this would change if the role of each pathway were to be identified and individual responsibilities among stakeholders demonstrated. Regional integral assessments such as the above matrix could assist managers to achieve this, increasing the likelihood of getting all stakeholders actively involved in regional NIS strategies, even under differential management of pathways. Finally, integral assessments would provide more robust baseline information for making vector management compulsory between specific regions and pathways, as suggested for vessels visiting the Kermadec and Sub-Antarctic island regions(Floerl et al. 2010a) and is currently the case with recreational vessels visiting Fiordland (Sinner et al. 2009).

The integral assessment described here is nevertheless limited to the initial steps of an NIS (accidental or deliberate) introduction. Connectivity between sub-regions determines whether or not the first critical stages of invasion (i.e., transport and arrival) could occur. It also has a determining effect on NIS propagule pressure, which is probably the most useful variable for predicting biological invasions (Reaser et al. 2008). Several authors have found that invasion success is best explained by high propagule count (e.g., Lockwood et al. 2005, Von Holle and Simberloff 2005, Lockwood et al. 2009). Nevertheless, transport between sub-regions and NIS arrival into a new area (regardless of the propagule pressure) does not imply establishment, as not all introductions are successful (Williamson and Fitter 1996).

For example, Simberloff (1997) estimated that of 154 reported species introduced to Florida (US), only 42 have actually survived and established. Several introductions of the American oyster *Crassostrea virginica* and Portuguese oyster *C. angulata* in coastal waters of Northern Europe largely failed (Neudecker 1992, Wehrmann et al. 2000, Wolff and Reise 2002). Similarly, although canoes have the potential to act as frequent dispersal vectors between portage-connected lakes, portage connectivity does not explain establishment success of canoe-mediated dispersal for crustacean zooplankton in Killarney Provincial Park in Ontario, Canada (Stasko et al. 2012).

6.3 FUTURE DIRECTIONS: FROM REGIONAL TO NATIONAL AND INTERNATIONAL MANAGEMENT

Management of regional pathways is likely to be ineffective, or at least considerably less efficient, if steps are not taken to prevent initial NIS introductions. Biosecurity strategies in many countries, including New Zealand, target management across international, national and regional levels (pre-border, border and post-border management) (Hewitt et al. 2004). This however, requires an understanding of pathways at all these levels.

The pathway modelling and prioritisation concepts presented in this thesis are a simplistic representation of reality (as with any model) but still practical and effective and fill a significant information gap. Apart from the fault tree analysis for recreational vessels (Chapter 2), for which development is time consuming and the data requirements onerous, the models are simple to implement and the required data can be easily collected or generated. These models could therefore be used to analyse other pathways in the Golden Bay and Tasman Bay region (e.g., research, recreational fishing) and could also be applied in other regions of New Zealand and internationally, and with other pathways and spatial scales.

The CR (Chapter 3, Chapter 5) for example, could be readily used to assess other domestic pathways in New Zealand such as the marine aquarium trade and public aquaria, which apart from opportunistic research (e.g., Smith et al. 2010b) to date have received limited attention. The CR could be used to assess the connectivity of these pathways at a global scale. For example, the analysis of currently available data on exports and imports of ornamental marine organisms worldwide (e.g., Wabnitz et al. 2003) using the CR is likely to be a straightforward task. Also, the PRV (Chapter 3) could be used to prioritise biosecurity management and research in such pathways at regional, national, and international level. The application of both measures (CR and PRV) is not limited to marine biosecurity, as the same (or at least equivalent) concepts and components are present in pathways for NIS terrestrial and other aquatic environments (e.g., NIS source and recipient area, wharves and boat ramps, vessel ≈ aeroplane, port ≈ airport,).

The pathway modelling, connectivity and management prioritisation concepts, as well as integral assessment (Table 6.1) presented here could be readily modified to be taxa- or species-specific (e.g., tunicates, macroalgae, *Ciona intestinalis, Undaria pinnatifida*), so if data on the environment considered and the species' habitat requirements are available, the likelihood of establishment can be assessed and included in the analysis (e.g., Pearce et al. 2012).

Similarly, the elicitation methodology and fuzzy logic (i.e., interval type–2) approach (Chapters 2, Chapter 3, Chapter 4) could be used to successfully apply (i.e., gather, generate, model, average, and present) expert opinion to research and management of biological invasions. The methods and concepts presented could therefore assist to implement integral management actions across pathways at different spatial levels to improve biosecurity strategies in New Zealand and elsewhere.

From a marine biosecurity perspective, compared to other regions and countries (Europe, US, Australia) New Zealand is privileged because of its: 1) geographic isolation, 2) low population, 3) biosecurity-specific regulating framework (see Allen+Clark 2012 for details), and 4) lack of internal political borders. The first two characteristics imply a relatively low level of vector activity, while the latter two (at least in theory) allow less complex design, implementation, compliance monitoring, and enforcement of biosecurity plans and regulations. All these characteristics together, are likely to facilitate improvements in the management of NIS domestic human-mediated pathways across the country. This certainly facilitated the analysis of the recreational boating, aquaculture and natural spread pathways in the study region. It is then possible that modelling regional pathways elsewhere (e.g., with complex political boundaries), or international pathways is more challenging, but still feasible. The same holds true for using CR and PRV, which have a generic design making them applicable to different scenarios with minor modifications (e.g., Chapter 2, Chapter 4).

Biosecurity today is considered integral to conservation programs worldwide. However, the wide range of realised and potential NIS incursions, as well as their drivers and uncertain future, turn biosecurity into a vast field largely unexplored. In this scenario, any research and management efforts appear modest. Contributions such as the present thesis are nonetheless valuable to biosecurity and thus, a base for conservation of ecosystem

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GLOSSARY

advection	Horizontal and vertical dispersal of organisms, propagules, particles, and heat, by the movement of oceanic, coastal, estuary or riverine water currents (GISP 2004, 2008).
alien species	see *non-indigenous*
anchorages	Areas identified by navigation charts, cruising books and vessel users as good places for recreational vessels to lie at anchor. These areas are sheltered and their seabed provides a suitable substrate for the anchor to hold. They are also known as anchoring areas.
anchoring heuristic	The tendency to provide subjective assessments or values similar to one/s already proposed (Slovic and Lictenstein 1971).
availability heuristic	The tendency for events and outcomes to appear more probable when they come to mind more easily (Clayton and Myers 2009).
ballast water	Water brought on board a vessel to increase the draft, change the trim, regulate the stability, or to maintain stress loads within acceptable limits (NRC 1996).
baseline port survey	A biological survey aimed at finding and identifying all introduced marine species that may be present in a port (Hewitt and Martin 2001).
bilge	The lowest internal portions of hull of a vessel (m-i-link.com n.d.).
bilge water	Any water and other liquids (including associated sediment) that accumulate in the bilge spaces (m-i-link.com n.d.).
biofouling	see *fouling organism*
bioinvasion	A broad term that refers to both human-assisted introductions and natural range expansions (Carlton 2001)
cryptogenic species	A species that is neither demonstratively indigenous nor non-indigenous (Carlton 1996).
dispersal	The movement and subsequent breeding of individuals from one area to another (Ramakrishnan 2008).
dispersion	This word has several meanings depending on the field where it is applied. When dealing with mass transport it is defined as the combined effect of advection and diffusion acting in a flow field with velocity gradients (Marion 2008); the spreading of particles from a source point (Thorpe 2009). Conversely, dispersion in ecology refers to the way in which individuals are arranged in space, relative to each other (Haag and Tonn 1998, Karleskint et al. 2011).
endemic species	Species with a distribution limited to only one defined area (e.g., a country, ecoregion, or island) (Kareiva and Floberg 2008).
entrainment	Uptake of any species from its natural or introduced range by potential vectors such a ballast water or fishing gear.
exotic	Ambiguous term for describing non-indigenous species (GISP 2008).
fouling organism	Any plant or animal that attaches to natural and artificial substrates such as piers, navigation buoys, hulls, and aquaculture gear. Includes crawling and nestling forms as well as seaweeds, hydroids, barnacles, mussels and many other taxa (Carlton 2001, GISP 2008).
fundamental niche	Describes all possible combinations of resources and conditions under which species' populations can grow, survive, and reproduce (Booth and Murray 2008).
hapū	Kinship group, clan, tribe, subtribe (Moordfield 2011)
hawser pipe	Steel pipe through which the hawser or cable of anchor passes; located in the ship's bow on either side of her stem; also known as chain pipe (m-i-link.com n.d.).
hawser	Large steel wire or fibre rope used for towing or mooring

hazard	'Something' (an object or event) that has the potential to cause harm under specific conditions that allow that risk to be realized (GISP 2004, 2008).
heuristics	strategies using readily accessible, through loosely applicable, information to manage problem solving in human beings and computers (Judea 1983).
incursion	Unauthorised entrance or movement of a non-native species into a region or country where it is not already established (Biosecurity Council 2003). For simplicity, unless clearly indicated otherwise, this thesis uses the terms *incursion* and *infection* interchangeably. This is also in line with the 'infection location' concept presented by Hayes (2002a) and used in the thesis.
indigenous species	A species naturally distributed (not *introduced*) within the region of interest.
infection mode	Ways in which components (e.g., deck of a vessel, aquaculture gear) can be 'infected' with NIS and include fouling and retention of water and/or sediment (Hayes 2002a).
infection	The outcomes of inoculation dependent on the strength and viability of the inoculums plus the degree of exposure to inoculations and intrinsic 'health' of the receiving 'host' environment—non-indigenous species 'infection' of ports, coasts, vessel, etc.—(GISP 2004).
inoculation	Any *ballast water* discharge or transfer of biofouled material containing organisms not native to the receiving environment (GISP 2004).
internal borders	Analogous to national borders for biosecurity, they are in a geographic sense, the various points post-border (between the locality of a new incursion and the values at risk) where management intervention is possible (Forrest et al. 2009).
introduced species	see *non-indigenous*
invasion resistance	This term refers to the varying abilities of native communities to prevent invasions (Elton 1958). It is also refered to as *biotic* resistance.
invasive species	Widespread non-indigenous species that have adverse effects on the ecology, economy and/or human health of the invaded region (Colautti and MacIsaac 2004). This term also applies to those native species that cause similar harm (Executive Presidential Order 1999).
iwi	Māori term that refers to an extended kinship group, tribe, nation, people, nationality, race - often refers to a large group of people descended from a common ancestor (Moordfield 2011).
kaimoana	Māori word for seafood (Moordfield 2011).
keel	A line of plates running along the centreline of a ship's bottom forming the backbone of the ship frame; usually thicker than other plates beside it (m-i-link.com n.d.).
marinas	Facilities comprehensively designed for the accommodation of vessels. Marinas are usually made of concrete structures, wooden pilings and floating pontoons. They can have berths, swing moorings and pile moorings for securing vessels, as well as anchoring areas.
marine farms	Collection of fixed and floating structures especially designed for activities of breeding, cultivation, on-growing or harvesting of shellfish, including spat catching and holding. These structures are comprised of submerged concrete blocks, wooden pilings, buoys, ropes, chains, wires and stainless steel frames, among others.
mooring	A structure used to secure recreational vessels.
mooring area	Locations where at least one mooring has been set up.
native species	see *indigenous species*
niche areas	Parts of the hull of a vessel that are particularly susceptible to biofouling growth due to different water flow conditions, the exposure of the anti-fouling coating system to wear, or areas

	that may be inadequately coated. These areas include propellers, thrusters, rudder, and hinges, among several others (ASA 2007).
pathway	The vector, the reason why the species is moved, and the route followed when moving the species (Carlton 2001).
pest management	Application of a suit of mechanism for the eradication or control of invasive species once established or introduced (Shine et al. 2000).
pest	An organism that has characteristics regarded as injurious or unwanted.
primary invasion	Initial establishment of an invasive marine species in a disjunct region (i.e., located beyond a land, ocean or temperature/salinity barrier) (GISP 2004, 2008).
propagule pressure	The product of propagule number (the number of introductions events) and mean propagule size (the number of individuals per event), or the sum of all introduction events of the number of individuals liberated (Lockwood et al. 2009).
propagules	Dispersal agents of organisms, including spores, zygotes, cysts, seeds, larvae and self-regenerative tissue fragments (GISP 2004, 2008).
propeller	a hub with three or more blades projected from it and secured to the aft end of the propeller shaft by key (m-i-link.com n.d.).
realised niche	In contrast to the fundamental niche, the realised niche describes the more limited set of resources and conditions necessary just for the persistence of species' populations in the presence of competitors and predators (Booth and Murray 2008).
reservoir	An epidemiological term for invasive species population/s which breed in uncontrolled locations to provide propagules or recruits that can spread to other areas (GISP 2008).
risk	A measure of the likelihood and severity of adverse effects (Lowrance 1976).
risk analysis	the process comprised of risk assessment developed around the concept that aspects of the event/activity considered could bring negative consequences (North 1995).
risk assessment	The process of characterising the risk based on the probability of occurrence and consequence (Byrd and Cothern 2000)
risk communication	The exchange of information and opinion concerning risk and risk-related factors among the risk assessors, risk managers, and other stakeholders (Fjeld et al. 2007).
risk management	The process where, based on information from risk assessment, decision makers evaluate and compare decision alternatives (Lane and Stephenson 1998).
rudder	a device that is used to steer a ship; a common type has a vertical fin at the stern (after end of the vessel) and is able to move from 35 degrees (m-i-link.com n.p.)
sea chest	small underwater compartment within the shell plating through which sea water is drawn in or discharged (m-i-link.com n.p.)
secondary introduction	The dispersal of a NIS beyond its primary location of introduction (Galil and Bogi 2009).
shell plating	The plating that forms a the hull of a vessel hull (m-i-link.com n.p.)
slipways	Inclined concrete ramps that extend out into the sea for launching and retrieving vessels. They are usually equipped with a cradle that helps to support the vessels when out of the water.
taiapure	A spatial closure to set aside coastal fishing areas which customarily have been of special significance to an *iwi* or *hapū* as a source of food (*kaimoana*) or for spiritual or cultural reasons.
tangata whenua	Māori term to refer to the indigenous people of the land (Moordfield 2011).

thrusters	A propeller or water jet device set into the hull to improve manoeuvring or assist accurate positioning (m-i-link.com n.d.).
translocate	Any deliberate or unintentional transfer of an organism or its propagules between disjunct sites (GISP 2008).
underspecificity	A type of linguistic uncertainty that occurs when there is unwanted generality (Regan et al. 2002)
unwanted organism	Any organism that a chief technical officer believes is capable or potentially capable of causing unwanted harm to any natural and physical resources or human health (Biosecurity Council 2003).
vector	The physical means or agent causing a species translocation such as ballast water, ships' hull, recreational vessels, or packing material (Carlton 2001).
wharves–jetties	Fixed platforms, commonly on wooden or concrete pilings, built parallel to and alongside the shoreline. A wharf/jetty permits vessels to come alongside in a reasonable depth of water to load and unload.

APPENDICES

Appendix A: Chapter 2

A.1 EXPERT INVITATION AND FIRST ELICITATION EXERCISE–EXPERT PANEL 1

Invitation to Participate in an Expert Panel on Marine Invasions

Dear *Expert*,

I am a PhD student from Auckland University of Technology and my research project is on marine invaders in the Golden-Tasman Bay area. The project is a part of Cawthron Institutes' marine biosecurity research programme. The general objective of my project is to develop a regional risk assessment model for Golden-Tasman Bay, integrating current and potential invasion pathways (e.g. regional boating routes and aquaculture trade).Information on marine invasion processes in New Zealand and around the world is relatively scarce and often case-specific which makes the design, implementation and validation of reliable invasion models somewhat challenging.

One of the most common alternatives to overcome the problem of scarce and/or absent data in risk assessment and analysis processes is the use of *Expert Opinion*. Experts, defined as people who have knowledge on a particular subject at an appropriate level of detail, are consulted in order to use their opinion as baseline information for the developing and/or validation of risk models.

I am currently working on the recreational boating pathway in the Golden-Tasman Bay region. Although I have collected some data which has helped me modelling this pathway, there are still many information gaps in the model. Therefore, I want to identify a panel of experts whose knowledge could bring valuable input into this model, and thus reduce or eliminate some of these gaps.

I understand that you work, or have worked, in at least one of the following fields: invasion biology, risk analysis, statistics, marine biology and recreational boating. For this reason, I believe that your opinion would be valuable to this project, and I would like to ask you to participate as a panel member.

As an expert of the panel, you will be contacted between 1-4 times with questionnaires. Questionnaires will be sent as email attachments and they will take no more than 1 hour to be filled out. You will have up to 2 weeks to return the questionnaires by email. The information you provide in these questionnaires will be anonymous and will only be used for the purpose of this research, which has no commercial implications.

Please let me know if you are willing to participate as a member of the group. If you are unable to participate I would appreciate it if you could let me know of anyone else whose knowledge in the above mentioned fields makes them a potential expert for the panel.

If you have any questions about this project please do not hesitate to contact me.

Thank you in advance for your collaboration.

Yours sincerely,

Hernando Acosta
Earth and Oceanic Research Institute
Auckland University of Technology
ph: 09 917 9999 ext 8185
hernando.acosta@aut.ac.nz

Date

Dear ***Expert***,

This is the first exercise of the *Expert Panel on Marine Invasions*. Following there is a description of the objectives and methodology of the exercise. Please do not hesitate to contact me if you have any questions about it.

Objectives
This exercise has two specific objectives:

1. to develop a general conceptual model for the marine invasion process via recreational vessels.
2. to identify the specific steps that have to be considered when assessing the risk of release of individuals of a non-indigenous species from an infected vessel into the environment.

Methodology
To complete this exercise please follow these steps:

1. read the baseline information essential for the exercise (section 1).
2. analyse the conceptual model provided (section 2) and make the changes you consider necessary.
3. email or post your comments to me.

Baseline Information
This information has been provided so all the participating experts share at least some baseline information on the marine invasion process and modelling technique used (i.e. fault tree analysis). You might have a sound knowledge on some (or all) of the topics briefly explained in this section. However, some of the other experts might have limited knowledge on some of these topics.

Conceptual model
The conceptual model provided in this exercise identifies all the general steps that need to be considered when assessing the risk of infection of an area via recreational vessels. The model however, is mainly focused on the sequence of necessary steps for the arrival of an infected vessel in a specific area and the events that could lead to the release of the non-indigenous species into this area.

Changes
You can make your changes directly on the **electronic copy** provided and email them back. Alternatively, you can make the changes on a **hard copy** and post it back to:

Auckland University of Technology
Private Bag 92006
Auckland 1020
Attention: **Hernando Acosta**

If you are in New Zealand you can free-post it by simply adding “Freepost 3401” before “Auckland University of Technology”.

Date of return
I would appreciate if you return your changes before December 21, 2005 (i.e. in three weeks time)

Thanks for your participation in this panel.

Regards,

Hernando Acosta

1

1. BACKGROUND INFORMATION

This section gives a brief description of the problem of *marine invasions* and the role of *recreational boating* in this problem. It also gives basic information on the modelling technique *Fault Tree Analysis.*

1.1. MARINE NON-INDIGENOUS SPECIES

Non-Indigenous species (NIS) can be defined as species which are beyond their natural ranges or natural zones of potential dispersal (U.S. Congress, Office Technology Assessment, 1993). Non-indigenous species are considered, after habitat destruction, the second most important threat to biodiversity around the world (Vitousek et al. 1997). Although terrestrial and freshwater invasions have been widely documented and studied for decades (e.g. Elton 1958, Simberloff 1996), only recently have marine invasions been acknowledged and researched (Williams et al. 1988; Carlton 1996). To date, representatives from over 10 phyla and 7 divisions with taxa representing different life history characteristics have been recognised as marine and estuarine invaders (Hewitt et al. 2001). However, this list underestimates the real number, due to the presence of populations of introduced species that can go un-noticed for a number of years (as was the case of the polychaete worm *Hydroides ezoensis* in Britain (Eno et al. 1997)) and the presence of cryptogenic species (species which native origin is unclear) (Carlton 1996).

1.1.1. Effects of Non-Indigenous Species

Non-indigenous species can have detrimental effects on the environment (Carlton, 1996). They can compete with and prey upon native species (Eldredge 1994), change physicochemical and nutrient conditions of the benthos (MoF, 1996), alter marine communities (Holloway and Keough, 2002) foul jetties, marinas and buoys (Hewitt et al. 2001). Non-indigenous species also can bring with them diseases and parasites to which native species are not resistant (Font et al. 1994).

The effects of NIS can be economically disastrous (Carlton, 1996). For example, the invasion of the comb jelly *Mnemiospsis leidy* in the Black Sea reduced the anchovy fisheries from hundreds of thousands of tons to tens of thousands, thus collapsing a fishery worth US$250 million/year (Harbison and Volovik, 1994). Similarly, the European green crab *Carcinus maenas* has been linked to the decline in the scallop fishery in the northeast US (Fincham, 1996).

1.1.2. Recreational boating as an Invasive Mechanism

Several invasion vectors have been identified for marine and estuarine species (Carlton, 1996). These vectors include commercial shipping, aquaculture and fishing industries, the aquarium trade, restoration projects and recreational boating, among others. Although commercial shipping, especially ballast water and hull fouling, had received most of the research attention, it is now well known that pathways like recreational boating are important mechanisms for the transportation and spread of NIS. For example, recreational boating has been implicated in the dispersal of the Asian Kelp *Undaria pinnatifida* in New Zealand (Forrest et al, 2000). The introduction and further spread of the black-striped mussel *Mytilopsis* spp. to Darwin (Australia) has been related to yachting activities (William et al, 2000).

A study on commercial fishing vessels and recreational vessels (displacement and trailerable) identified seven vessel components that can be infected with NIS (Hayes, 2002): 1) hull, 2) deck, 3) internal spaces 4) fishing gear, 5) propeller, 6) rudder and 7) anchor. These components were subsequently divided into subcomponents, identifying the way(s) they could become infected (i.e. their *infection mode*) (see Appendix A). A total of eight infection modes were identified: 1)external fouling (visible when vessel is either in or out the water), 2)internal fouling (hidden from view), 3)borer (organisms that bore into wooden or fibreglass surfaces), 4)refuge (harbours an organism *visible to the naked eye*), 5)retained water (water retained when vessel is either in or out the water), 6)retained sediment (sediment retained when vessel is either in or out the water), 7)catch parasites (catch infected with non-indigenous parasites) and 8)bait (bait or parasites on the bait are NIS).

1.2. Fault Tree Analysis as a modelling tool in the marine invasion processes.

Fault tree analysis is a common technique used in engineering for formalising conceptual models (Burgman, 2005). Fault trees have been largely used in safety and diagnostic studies (e.g. failure of engines) and in the designing of new products and services (e.g. software and hardware design) (Andrews and Moss, 2002). Fault trees have been also used in the ecology area. For example, the IUCN protocol used to assess the risk of extinction of species is based on a fault tree analysis. However, the applicability of this technique in the modelling of marine invasive processes had been basically ignored. Only recently, when a fault tree was developed for the ballast water introduction cycle (Hayes, 2002,b) was the potential of fault tree analysis in this field demonstrated. This fault tree identified all the combinations of events that could lead to an infection of a recipient port when ballast water is discharged. It also highlighted the lack of information on parts of the process (e.g. effects of the ballast pump on survival and the risk of third-party hull fouling), which are important source of uncertainty when assessing the risk of introduction via ballast water.

1.3. Fault Tree Analysis Methodology

Fault Tree Analysis is a technique that graphically analyses the system from the top to bottom, identifying the occurrence of an event (the *top event*) as the result of the occurrence or non-occurrence of other (intermediate) events. *Intermediate* events are also described further until the *basic* or *undeveloped* events are identified. *Basic* events require no further development because an appropriate level of resolution has been reached. *Undeveloped* events required no further development because information is unavailable or because its consequences are insignificant. Using the logic functions *OR* and *AND*, a fault tree analysis represents graphically all the parallel and sequential combinations of events that could make the *top event* occur. A list of the symbols commonly used in fault tree analysis is provided in Figure 1.

Intermediate events have only one input which can be a basic event, an undeveloped event or a logic gate (OR or AND). Logic gates can have any number of inputs. These inputs can be intermediate, basic events and/or undeveloped events. The resulting event of an OR gates occurs if one or more of the inputs occur. The resulting event of an AND gate occurs only if all the input events occur.

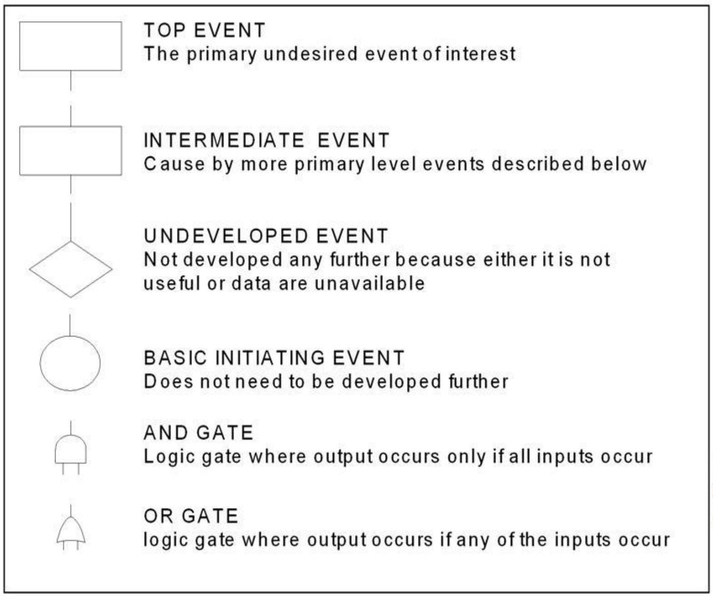

Figure 1. Commonly used symbols in Fault Tree Analysis (from Andrews & Moss, 2002)

1.4. Fault tree analysis example

The following figure (Figure 2) and fragment extracted from the article published by Hayes (2002,b) is a good example of the sequential approach used when developing a fault tree analysis.

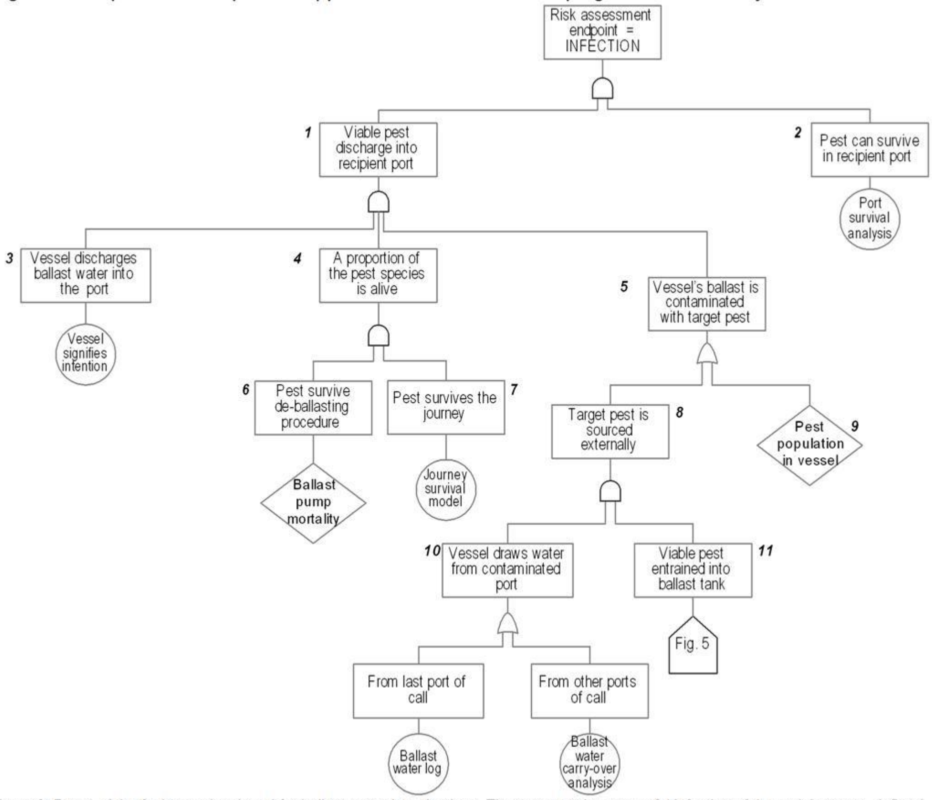

Figure 2. Part 1 of the fault-tree developed for ballast-water introductions. The top event is successful infection of the recipient port, defined here as the introduction of a non-indigenous species (the target pest) into a port where it can survive. This part shows all necessary events between entrainment of a viable organism in the ballast tank and infection of the recipient port (from Hayes 2002,b).

"…The top event in this instance is successful infection of a recipient port. Successful infection of the recipient port (a port that receives ballast-water from a vessel) occurs if:

- a viable (i.e. alive) organism is discharged into the recipient port (1); AND,
- the organism is capable of surviving in the port (2).

The probability that the organism will survive in the port is an undeveloped event. This can be calculated by comparing, for example, the temperature and salinity characteristics of the port with the temperature and salinity tolerances of the species concerned…Three events must occur for a viable organism to be discharged into a recipient port:

- the vessel must discharge its ballast-water into the port (3); AND,
- some proportion of the target species in the ballast water must be alive (4); AND,
- the vessel's ballast-water must be contaminated with the target species (5).

There is no need to develop the first event further –the vessel either does or does not need to deballast and can signify its intention accordingly….For an organism to be alive when discharged from a ballast-tank, it must:

- survive the deballasting procedure (6); AND
- survive the vessel's journey (7).

The effect of ballast pumps on the subsequent survival of organisms has not been sufficiently well researched to develop it further in the fault-tree….Journey survival is not developed further in the fault-tree because it can be explicitly modelled…"

4

2. CONCEPTUAL MODEL

This section is comprised of three parts. The first part gives some instructions on how to analyse the model and make the changes. The second describes how the model was developed, while the final part provides the existing model.

2.1. INTRUCTIONS

Please read the following instructions in order to make your changes to the fault trees.

1- Read and analyse the conceptual model provided in this section thoroughly. Remember that definitions and assumptions are essential parts of the model so please consider them during your analysis.

2- Make all the changes you think are required in order to make the model more comprehensive and realistic.

a. If you consider that the model does not need any changes, please indicate so.
b. You can add, delete or modify any of the definitions, assumptions, components, events, and relationships.
c. You do not need to justify your changes but if you are able to provide an example and/or reference relevant to your change(s), please do so.

If there is **ANYTHING** in the model, (e.g. terms, components, relationships between events) that you do not understand, please contact me for further explanations.

Please do not discuss the model with anybody else. This could affect your perception of the problem and interpretation of the model, and thus, your answers.

2.2. HOW TO MAKE YOUR CHANGES TO THE MODELS:

As mentioned before you can either make your changes directly on this document or print out a hard copy of the document and make the changes on it.

2.2.1. Changes on this electronic copy

I do not mind which method you use, as long as I can identify and understand the changes you have made.

If you are going to make the changes directly on this electronic copy, you might want to use one of the following options:

Adding Comments and/or Changing Definitions and Assumptions: You can type your changes directly on this word document. You are welcome to use a different font colour for your changes. It is fine however, if you want to use the original font colour (i.e. **black**) as your changes could be tracked using the "Track changes" option from *Microsoft Word*.

Adding changes to a Fault Tree:

- *Using the Drawing Toolbar of Word:*

You can superimpose your changes on the image of the fault tree you want to modify using the Drawing Toolbar available in Microsoft Word. For this, you have to activate the Drawing Toolbar (go to View Menu, select Toolbars, and then click on Drawing Toolbar). Once this toolbar is active you can use the drawing box, line, rectangle and oval options to modify the fault trees.
You can add any comments, examples or references at the end of each figure. Please use the figure number and event number so that I know where your change, comment, reference or example is relevant.

Table 1. Vessel components and infection modes used for the Fault Tree analysis.

Vessel component	Infection Mode
Hull, Propeller and Rudder	Fouling
	Refuge
Deck	Water/Sediment retention
	Refuge
Internal Spaces	Fouling
	Water/Sediment retention
	Refuge
Anchor	Fouling
	Water/Sediment retention
Fishing gear (including Diving gear)	Fouling
	Water/Sediment retention
	Refuge

2.3.3. Definitions and Assumptions

The model uses the following definitions and assumptions:

- **Assumptions**

1. Cruising patterns of Vessel S area known.
2. User of Vessel S does not take any specific control measures to prevent entrapment of species S in Area Y, and further transport of it to Area Z.
3. When Vessel S is in Area Z, it may or may not have contact with marine structures (e.g. marinas, wharves, anchorages, etc).
4. Vessel S has five different components that can be infected by species S: 1)*Hull, Propeller and Rudder*, 2) *Deck*, 3) *Internal Spaces*, 4) *Anchor* 5) *Fishing Gear* (including Diving gear) (see Table 1).
5. If species S can tolerate certain environmental conditions, its spawn can tolerate similar conditions.

- **Definitions**

Automatic discharges occur without the intervention of the user of the vessel. They are carried out by pumps equipped with float switchers and/or sensors (e.g. automatic bilge pumps).
Cleaning habits covers all the information about the cleaning of the vessel. It includes information about the components and subcomponents that are cleaned (e.g. hull, gunwale, bilges), how often these components and subcomponents are cleaned and the cleaning method used (e.g. waterblasting, scraping).
Cruising habits defines regions visited by the vessel, cruising routes followed to get to those regions and launching/mooring/anchoring locations used.
Discharge is the release of any element, liquid or solid, organic or inorganic, from a boat into the sea. Although discharge may be part of a cleaning process, discharge by itself is not considered as cleaning.
Disturbances refers to changes in the physicochemical and hydrodynamic characteristics of the environment considered (e.g. temperature, salinity, exposure to water drag). These changes are abrupt and do not represent the natural variation of these characteristics (e.g. daily, seasonal). They are usually generated by external components of the environment considered (e.g. turbulence in the bilge of a yacht generated by storm weather).
Environmental Data is any measurements or information on biological, physicochemical and hydrodynamic processes that describe a location (e.g. a bay, a marina or the bilge in a yacht). Environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as databases or the literature.

Infection location identifies the exact place on the vessel component where the NIS is present (e.g. exhaust outlet).
Mobility is the ability of a species to move on its own in the environment considered (e.g. crabs are able to move in the water and on the land, and on the deck of a boat).
Recreational boating is the activity related to the use of recreational vessels (e.g. keelers, motor cruisers, small powered crafts). This can include sailing, cruising, recreational fishing and racing, among others.
Scrape is to make a surface smooth or clean with strokes of an instrument or an abrasive.
Spawn is a mass of eggs of a fish, amphibian, or other water animal.
Spawning is the action of releasing eggs or sperm by a water animal.
Species behaviour identifies the way species usually behave under specific environmental conditions. Species behaviour is directly determined by the characteristics of the species.
Species characteristics includes the biological and ecological characteristics of the species. The characteristics of a species will determine its tolerance to physicochemical conditions of the environment as well as its mobility.
User awareness refers to the vessel user's knowledge on the problem of marine invasions in general, and species S in particular.
User-controlled discharges only occur when the user of the vessel carries them out or initiates them (e.g. turning on the bilge pump, removing a drain plug).
Vessel activity defines the activity the owner is conducting with the vessels at a specific time. This includes cruising, mooring, anchoring, fishing, diving and drifting, as well as cleaning.
Weather conditions identify the state of the weather at a given time and place, with respect to variables such as temperature, wind velocity and direction, and barometric pressure.

2.3.4. THE MODEL

The model identifies the main events that must occur for Area Z to become infected with species S (Figure 3). Although the model develops the intermediate event *Arrive in Area Y* further, its main focus is on the release process (Figures 4-9).

Notes:

- All the events in the figures have been numbered based on their citation in the text. This means that **an event is referenced by the number of the figure and the number of the event in that figure**. For example, "*Vessel visits Area Y* (12)" means that this is the event number 12 in the figure that is being described.
- All the figures of the model have been attached at the end of this document.

INFECTION OF AREA Z (Figure 3)

The top event of the analysis, in this case "*Area Z becomes infected with species S*" (1), only occurs if all the following events occur (Figure 3):

- Species S arrives in Area Z (2); AND
- Species S is released into Area Z (3); AND
- Species S survives in Area Z (4).

Arriving in Area Z (Figure 3)

Two intermediate events must occur if an organism of species S is to arrive in Area Z on Vessel V:

- Vessel V arrives in Area Z (5); AND
- Vessel V is infected with species S (6).

The arrival of Vessel S in Area Z can be determined by the vessel's cruising habits (7) so there is no need to develop this event further. For Vessel S to arrive in Area Z infected with species S the following two events must occur:

- Vessel V becomes infected with species S in Area Y (8); AND
- Species S survives the trip from Area Y to Area Z (9).

The trip survival of species S depends on the interaction of several factors such as species characteristics, environmental conditions of the infected part and characteristics of the trip (e.g.

length). It is then necessary to develop specific survival models for each of the potentially infected components of the vessel (10). Vessel V becomes infected with species S in Area Y only if:

- Species S is entrained by Vessel V (11); AND
- Vessel V has contact with Area Y (12);

Vessel V has contact with Area Y because either:

- Vessel V is based (moored or launched) in Area Y (13); OR
- Vessel V visits Area Y (14)

These two events are determined by the vessel's cruising habits (15,16). However, whether species S is entrained by vessel V in Area Y is determined by the interaction of several factors (e.g. species characteristics, vessel activity). Therefore, entrainment models for each vessel component must be developed to analyse this risk (17).

Release in Area Z (Figure 3)
As any of the five components of Vessel V could be infected, each component is analysed as a potential source of species S (Figure 3). Thus, release of species S may occur from any of the following components:

- Hull, Propeller and Rudder (18); OR,
- Deck (19); OR
- Internal Spaces (20); OR
- Anchor (21); OR
- Fishing Gear (22)

Survival in Area Z (Figure 3)
A specific model has to be developed to estimate the likelihood of survival of species S in Area Z. This model must be based on the biology and ecology of the species and the environmental characteristics of Area Z (23).

RELEASE IN AREA Z (Figures 4-9)

Hull, Rudder and Propeller (Figure 4)
Two infection modes are considered for the Hull component: Fouling (2) and Refuge (3).

If species S is present in Vessel V as fouling (2), two events can lead to its release into the environment:

- Species S spawns into the water (4); OR
- Species S is dislodged into the water (5)

Spawning of species S can be a natural process (6) or an induced process (7). Information on the life cycle of species S (8) and environmental data of Area Z (9) (e.g. temperature, salinity) can be used to estimate the likelihood of natural spawning. Spawning can be induced by disturbances in Area Z. In order to determine whether disturbance induces spawning, it is necessary to identify the type of disturbances that can occur in the refuge and whether those disturbances can induce spawning in species S (10). Species S can be dislodged into the environment (5) by scraping (11) or water drag (12). Scraping can be the result of cleaning by the user (13) or contact with other structures (14). Whether the scraping action of the user releases species S into the water is determined by the infection location (15), cleaning habits (16) and user awareness (17). The structures that the hull component can have contact with are: berthing/mooring structures (18), other boats (19), sea bed (20), fishing gear (21) or the anchor (22). Whether there is contact with these structures, and this contact scrapes species S into the environment, is determined by the activity of the vessel and the infection location (23-32). In order to determine whether water drag dislodges species S, it is necessary to identify the infection location (33), the hydrodynamic forces that work on it and the force required to dislodge the species. All this information can be used to develop a dislodgment model (34).

If the species is using the hull as refuge (3), there are three ways in which species S can be released into the water:

- Species S is physically removed from the refuge (35); OR
- Species S leaves the refuge (36); OR
- Species S spawns into the water (37),

Species S can be removed from the refuge by water drag (38) or by the user (39). Whether drag removes species S from the refuge depends on the infection location (40) and the weather conditions (41). Similarly, the factors determining whether the user removes Species S from the refuge are infection location (42), cleaning habits (43) and user awareness (44). Whether species S leaves the refuge is determined by the species characteristics (i.e. mobility) and its behaviour vs. the environmental conditions of the refuge (45). Spawning of species S from refuge (37) can be modelled by the same events and factors mentioned above for spawning from fouling (46-49).

Origin Deck (Figure 5)
Two infection modes are considered for Deck: Water/Sediment retention (2) and Refuge (3).

If Deck is infected with Water or Sediment (i.e. species S is present in either), three events can lead to the release of species S into the water:

- User discharges retained water/sediment into the sea (4); OR
- Rain washes retained water/sediment into the sea (5); OR
- Waves wash retained water/sediment into the sea (6).

The factors determining whether the user, rain or waves release retained water/sediment into the sea (7-13) are the same as those mentioned above for *Refuge* in the *Hull*.

If species S is using the deck as a refuge, three events can release it into the environment:

- Species S is physically removed from the refuge (14); OR
- Species S leaves the refuge (15); OR
- Spawn from species S is released into the environment (16).

Species S can be physically removed from its refuge by rain (17), waves (18) or the user (19). The factors determining whether these events occur (20-26) are the same as those mentioned above for water/sediment retention. Event '*Species S leaves the refuge*' can be modelled as mentioned before in the Hull component (27). Event '*Spawn is released into the water*' occurs only if species S spawns (28) AND the spawn reaches the water (29). Spawning of the species can be modelled based on the same events and factors (30-33) identified in the mode *Refuge* for the *Hull*. Whether the spawn reaches the water is determined by the location of the infection (34).

Origin Internal Spaces (Figures 6 and 7)
Three infection modes are considered for internal spaces: Water/Sediment retention (2), Fouling (3) and Refuge (4).

If Species S is present in the water/sediment retained, two events could release it into the environment (Figure 6):

- Discharge from internal spaces (5); OR
- Cleaning of internal spaces (6)

Discharge of water/sediment from internal spaces can occur automatically (7) or manually (8). The factors that determine whether species S is released by an automatic discharge process event are infection location (9) and weather conditions (10). Similarly, the factors that determine the release of species S by a user-controlled discharge are infection location (11), weather conditions (12) and user awareness (13). Whether the cleaning of internal spaces results in the release of species S into the water is determined by the infection location (14), cleaning habits (15) and user awareness (16).

If species S is present in the internal spaces as fouling (3), three events can lead to its release into the environment (Figure 6):

- Discharge processes dislodge species S into the water (17); OR
- User releases species S during cleaning (18); OR
- Discharge process releases spawn into the environment (19)

Species S is dislodged into the water only if there is discharge of the internal space (20) and if this discharge dislodges the species from the internal space (21). As with the retained Water/Sediment, the factors that determine whether there is discharge from internal spaces are infection location, weather conditions and user awareness (24-28). However, in order to determine whether the discharge process dislodge the species (21), it is necessary to have information on the force required to dislodge the species and the mechanical and hydrodynamic forces that work on the infected space (29). The factors that determine whether the user releases species S during cleaning are infection location (30), cleaning habitats (31) and user awareness (32). Spawn of species S is released into the water only if the species spawns into the internal space (34) and there is discharge from that space into the environment (33). Whether there is a discharge of the internal spaces is determined by the same factors mentioned above (35-41). The event '*Discharge of spawn released into the internal space'* (19) can be modelled by the same events and factors (42-46) mentioned for spawning events in the *Hull* component.

If the species is using internal spaces as refuge, three events can release species S into the water (Figure 7):

- Species S is physically removed from the refuge (2); OR
- Species S leaves the refuge (3); OR
- Spawn of species S is discharged into the water (4).

Discharge processes (5) and cleaning activities (6) can physically remove the species from the refuge. The events and factors that control whether discharge processes or cleaning removes species S (7-16) are the same as those mentioned above for retention of Water/Sediment. Whether the species leaves the refuge is influenced by the same events and factors (17) identified above for components *Deck* and *Hull*. Whether spawn is discharged into the water (4) is determined not only by the events and factors already mentioned in the Deck and Hull components for spawning (18, 20-24) but also by the factors that determine the actual discharge of internal spaces (19, 25-31).

Origin Anchor (Figure 8)
Two infection modes are considered for the anchor: Fouling (2) and Water/Sediment retention (3).

If the anchor is infected by fouling, the occurrence of at least one of two events can release species S into the environment:

- Species is released when anchor is deployed (4); OR
- Species is released when anchor is cleaned (5).

Species S can be released into the environment when the anchor is deployed either because the species is dislodged (6) or because the species spawns into the water (7). Species S can be dislodged from the anchor by scraping (8) or by water drag (9). Scraping of the anchor can occur as a result of contact with the seabed (10) or contact with fishing gear (11). Whether the seabed dislodges species S by scraping depends on the infection location (12) and bottom type (13). Whether the fishing gear dislodges the species from the anchor into the environment depends on the infection location (14) and vessel activity (15). In order to determine whether water drag dislodges species S, it is necessary to know the force required to dislodge species S and the hydrodynamic forces encountered when the anchor is deployed (16,17). The spawning process of species S from the anchor is modelled by the same events and factors identified for the spawning event in the Hull component (18-22). The factors determining whether the species S is released into the environment during cleaning (5) are infection location (23), cleaning habits (24) and user awareness (25).

If the infection of the anchor is by retained Water/Sediment (3), two events can released the species into Area Z:

- Water/Sediment is washed into the water when the anchor is deployed (26); OR
- Water/Sediment is discharge by user during cleaning (27).

The infection location (28) and the vessel activity (29) determine whether the retained Water/Sediment is washed into the water when the anchor is deployed. Similarly, infection location (30), cleaning habits (31) and user awareness (32) determine whether species S is discharged into the environment during the cleaning of the anchor.

Fishing gear (including Diving gear) (Figure 9)
Three infection modes are considered for the fishing gear component: Fouling (2), Water/Sediment retention (3) and Refuge (4).

The same events and factors (5-33) that model the release of the species from Fouling and retained Water/Sediment in the Anchor component are used to model these infection modes here.

If the species is using fishing gear as a refuge, three events can release species S into the water:

- Species S is physically removed (34); OR
- Species S leaves the refuge (35), OR
- Species S spawns into the water (36)

Species can be removed from the refuge by water drag when gear is deployed (37) or by the user during cleaning activities (38). Whether water drag removes the species depends on the location of the infection (39) and the ability of the species to withstand the hydrodynamic forces encountered (40). The factors that determine whether the user releases species S during cleaning are infection location (41), cleaning habits (42) and user awareness (43). Events '*Species S leaves the refuge'* and '*Species S spawns into the water'* are defined by the same events and factors (43-46) identified for the Refuge mode in the Hull component.

THANKS FOR YOUR TIME AND COLLABORATION

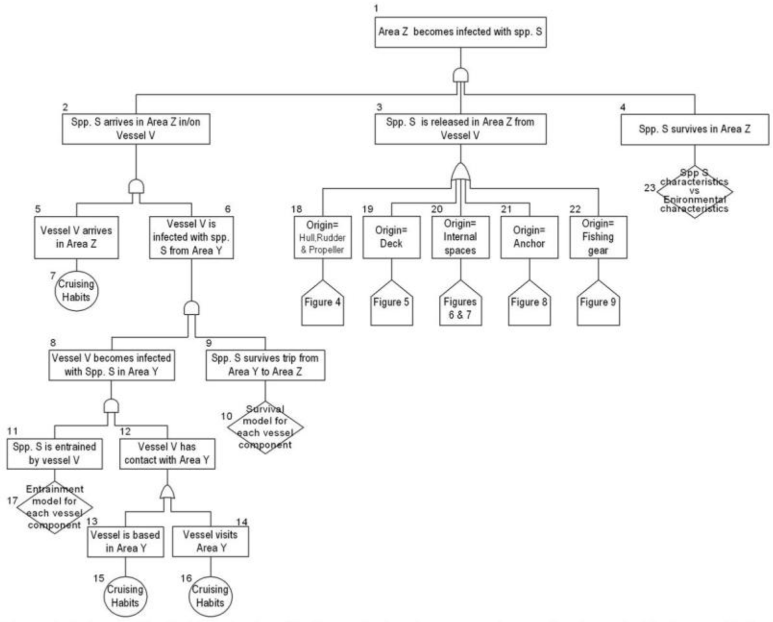

Figure 3. First part of the fault tree developed for the marine invasion process via recreational vessels. The top event is the infection of Area Z. The figure shows the sequence of events from the infection of the vessel V in Area Y to the release and survival of species S in Area Z.

13

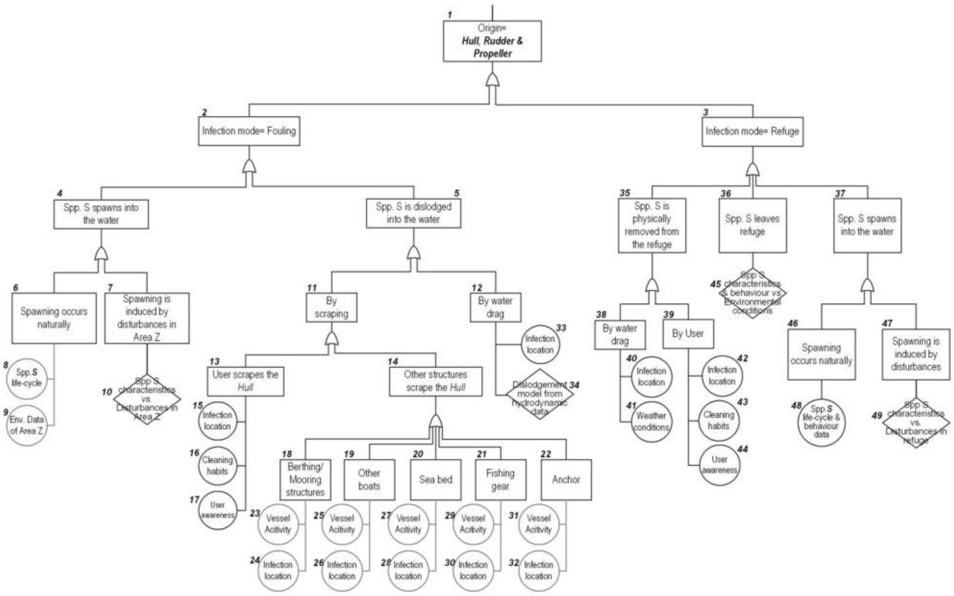

Figure 4. Release of species S from the *Hull, Rudder and Propeller component*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected.

14

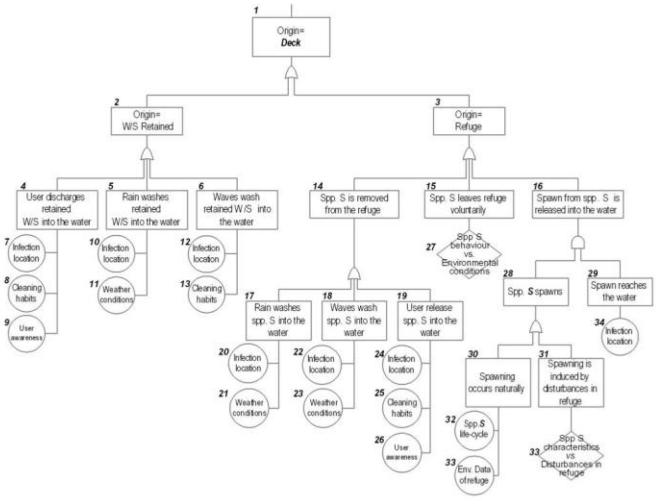

Figure 5. Release of species S from the *Deck component*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. W/S= Water / Sediment.

15

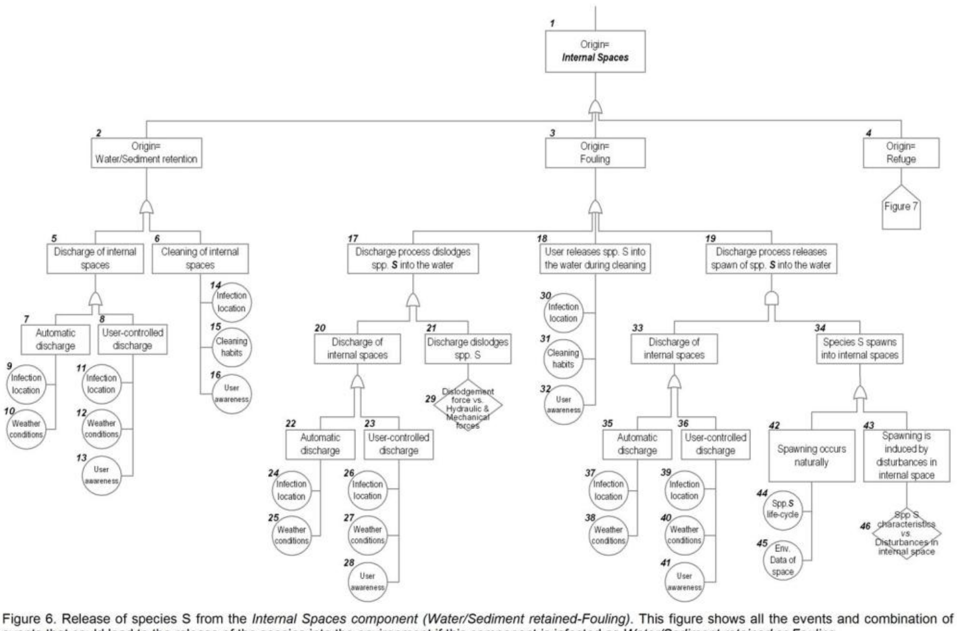

Figure 6. Release of species S from the *Internal Spaces component (Water/Sediment retained-Fouling)*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected as *Water/Sediment retained* or *Fouling*.

16

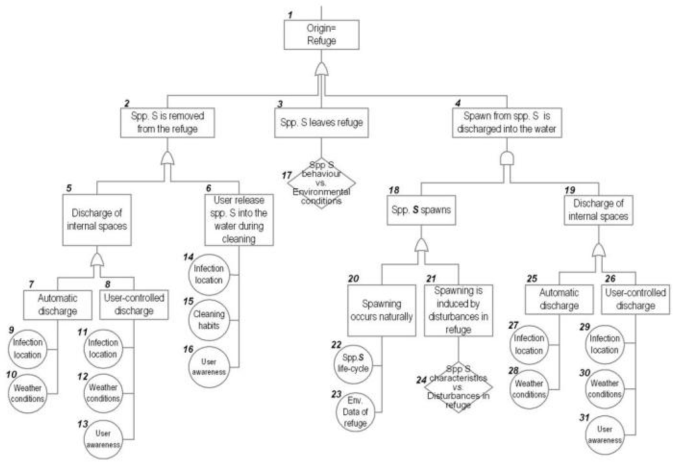

Figure 7. Release of species S from the *Internal Spaces component (Refuge)*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected as *Refuge*.

17

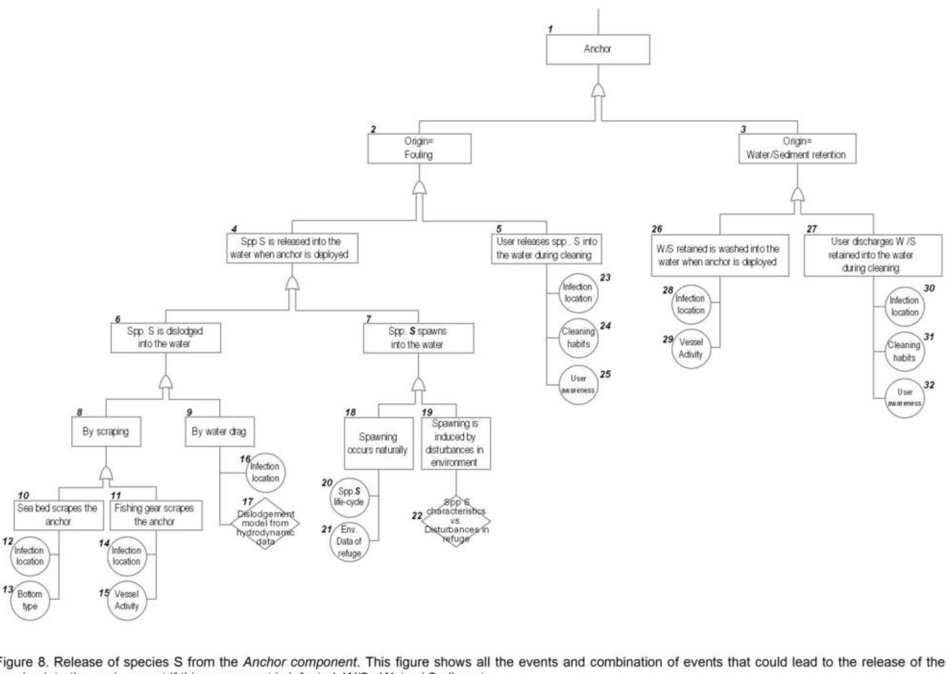

Figure 8. Release of species S from the *Anchor component*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. W/S= Water / Sediment.

18

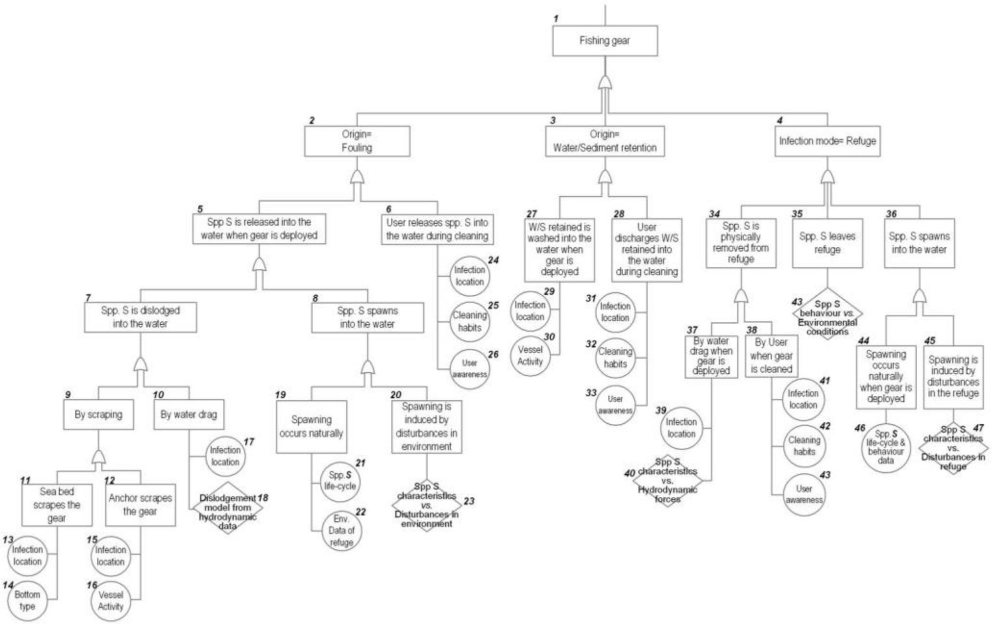

Figure 9. Release of species S from the *Fishing gear component*. This figure shows all the events and combination of events that could lead to the release of the species into the environment if this component is infected. W/S= Water / Sediment.

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A.2 EXPERT INVITATION AND FIRST ELICITATION EXERCISE–EXPERT PANEL 2

page 1 of 2

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced: 01 Sept 2010

Project Title: Marine biosecurity in Golden Bay and Tasman Bay, New Zealand

An Invitation:

Dear ***expert***,

I am a postgraduate student from Auckland University of Technology and my research thesis is on marine biosecurity in New Zealand, with focus on Golden Bay and Tasman Bay. As part of the research I am identifying the potential role of recreational vessels as vectors for marine non-indigenous species. Therefore, I am inviting you to participate in a series of surveys that will provide essential information for this research.

Your participation in the surveys is voluntary and you may withdraw at any time prior to the completion of data collection without any adverse consequences.

What is the purpose of this research?

The main objective of this research is to identify the components and processes of recreational boating that could have a role in the spread of marine non-indigenous species.

How was I identified and why am I being invited to participate in this research?

You were identified because either:

1- your name appears in publicly available reports and peer-reviewed articles related to at least one of the following fields: recreational boating, biosecurity, invasion biology, risk analysis or marine biology; or

2- I have met you before and know you work (have worked) in at least one of those fields.

You are invited to participate because I believe your knowledge would be valuable to this project.

What will happen in this research?

As a participant in the surveys you will be contacted via email with 5 questionnaires that will take between 45-60 minutes to complete each. You will have up to 10 days to complete each questionnaire and return it back to me by email/mail.

What are the discomforts and risks and how will these discomforts and risks be alleviated?

The survey has been carefully designed and tested with several people, who considered all the questions straightforward, easy to answer and not intrusive. However, if for any reason you do not feel comfortable answering a particular question, you do not have to answer it. Also, you may withdraw from the survey at any time before the collection of data with no adverse consequences.

What are the benefits?

The present project would produce baseline information on the dynamics of recreational boating as a pathway of non-indigenous species. Such information is essential for the implementation of effective monitoring and control programs of non-indigenous species.

How will my privacy be protected?

All the information you provide in the survey will be:
- not connected to your contact details in any way,
- kept confidential,
- only accessed by my supervisor and me,
- only used for the purpose of this research, and
- not shared with any other parties under any circumstances.

While there might be publications as a result of this study, your identity will remain anonymous as only averaged data and summaries will be presented.

What are the costs of participating in this research?

I know you are a busy person so I am only asking you for a maximum of 5 hours over a period of 2 months, approximately. You will NOT have to spend any money in postage as your answers can be emailed.

What opportunity do I have to consider this invitation?

I would really appreciate if you let me know no later than October 13, whether or not you are willing to participate.

How do I agree to participate in this research?

Simply fill out the *Consent Form* attached to this information.

Will I receive feedback on the results of this research?

Yes! If you are interested in receiving such a feedback, just tick this option in the *Consent Form*.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Andrea Alfaro, a.alfaro@aut.ac.nz , 921 9999 ext 8197.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz 921 9999 ext 8044.

Whom do I contact for further information about this research?

If you have any questions regarding this research please do not hesitate to contact me or my supervisor Dr. Andrea Alfaro

Researcher Contact Details:

Hernando Acosta
hacosta@aut.ac.nz
09-9219999 ext 8185
24 St. Paul Street, Auckland, New Zealand

Project Supervisor Contact Details:

Dr. Andrea Alfaro
a.alfaro@aut.ac.nz
09-9219999 ext 8197
24 St. Paul Street, Auckland, New Zealand.

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010, AUTEC Reference number 10/224.

Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***Marine biosecurity in Golden Bay and Tasman Bay, New Zealand***

Project Supervisor: ***Andrea Alfaro***

Researcher: ***Hernando Acosta***

☐ I have read and understood the information provided about this research project in the Information Sheet dated *01 Sept 2010*.

☐ I have had an opportunity to ask questions and to have them answered.

☐ I understand that questionnaires will be either self-administrated or filled out during the interview(s), and that additionally notes may be also taken.

☐ I understand that if an interview is conducted to fill out a questionnaire, additional notes may be also taken.

☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

☐ If I withdraw, I understand that all relevant information including questionnaires, emails, or parts thereof, will be destroyed.

☐ I agree to take part in this research.

I wish to receive a copy of the report from the research (please tick one): ☐ Yes
☐ No

Participant's signature:

Participant's name:

Date:

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010, AUTEC Reference number 10/224.

Note: The Participant should retain a copy of this form.

Marine invasions and recreational boating – Exercise 1

AUT UNIVERSITY

Date

Dear ***Expert***,

This is the first exercise of the Expert Panel on Marine Bioinvasions. Following there is a description of the objectives and methodology of the exercise. Please do not hesitate to contact me if you have any questions about it.

Objectives

This exercise has three specific objectives:

1. to develop a general conceptual model for the marine invasion process via recreational vessels.
2. to improve an existing model that identifies the specific steps that have to be considered when assessing the probability of releasing a non-indigenous species from an infected vessel into the environment.
3. to gather some basic information about the background of the contributing experts.

Methodology

To complete this exercise please follow these steps:

1. read the baseline information essential for the exercise (section 1).
2. analyse the conceptual model provided (section 2) and make the changes you consider necessary.
3. email or post your answers and comments to me.
4. answer some questions about your background (document "expert background.doc") and email it back to me.

Baseline Information

This information has been provided so all the participating experts share at least some baseline information on the marine invasion process and modelling technique used (i.e. fault tree analysis). You might have a sound knowledge on some (or all) of the topics briefly explained in this section. However, some of the other experts might have limited knowledge on some of these topics.

Conceptual model

The conceptual model provided in this exercise identifies all the general steps that need to be considered when assessing the probability of infection of an area via recreational vessels. The model however, is mainly focused on the sequence of necessary steps for the arrival of an infected vessel in a specific area and the events that could lead to the release of the non-indigenous species into this area.

Changes

You can make your changes directly on the **electronic copy** provided and email them back. Alternatively, you can make the changes on a **hard copy** and post it back to:

Auckland University of Technology
Private Bag 92006
Auckland 1020
Attention: **Andrea Alfaro / Hernando Acosta**

If you are in New Zealand you can free-post it by simply adding "Freepost 3401" before "Auckland University of Technology".

Date of return

I would appreciate if you return your changes before October 10 (i.e. in two weeks time)

Thanks for your participation in this panel.

Regards,

Hernando Acosta

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010. AUTEC Reference number 10/224

Marine invasions and recreational boating – Exercise 1

1. BASELINE NFORMATION

This section gives a brief description of the problem of marine bioinvasions and the role of recreational boating in this problem. It also gives basic information on the modelling technique Fault tree analysis.

1.1. Marine non-indigenous species

Non-indigenous species (NIS), also referred as *non-native, introduced, exotic* or *alien,* are usually defined as species which are beyond their natural ranges or natural zones of potential dispersal (U.S. Congress-Office of Technology Assessment 1993). Marine NIS are a leading cause of biodiversity loss (Lubchencon et al. 1991, Vitousek et al. 1997, Bax 2003), with a wide range of potentially irreversible ecological and socio-economic detrimental impacts being documented worldwide (e.g. Kelly 1993, Cranfield et al. 1998, Barbersi and Gherardi 2000, Galil 2000, Ambrogi 2001, Grosholz et al. 2000, Walton et al. 2002, Lewis et al. 2003, Rilov and Crooks 2009). Specifically marine NIS have been recognised to change physicochemical conditions in the invaded ecosystem (e.g. Wallentinus 2002) and to compete and prey upon native species (e.g. Ross et al. 2004). They can also bring with them a complement of NIS diseases and parasites to which native species may not be resistant (Torchin et al. 2003). Marine NIS can also have important socio-economic impacts (Carlton 1996, Colautti 2006), as they are likely to threaten income derived from aquaculture, commercial and recreational fishing, water sport industries and domestic and international tourism (e.g. Gomoiu 1981, Leppäkoski 1991, Galil 2000, Knowler 2005, Robinson et al. 2005)

1.2. Recreational boating as a vector for the spread of non-indigenous species

Several invasion vectors have been identified for marine and estuarine species (Carlton 1996, 2001, Hewitt 2004, Minchin 2007). These vectors include commercial shipping, aquaculture and fishing industries, the aquarium trade, restoration projects and recreational boating, among others. Although commercial shipping, especially ballast water and hull fouling, had received most of the research attention, it is now well known that pathways like recreational boating are important mechanisms for the transportation and spread of NIS. For example, recreational boating has been identified as a vector for the seastar *Asterias amurensis* (Hayes 2007), the Asian Kelp *Undaria pinnatifida* (Forrest et al. 2000), the clubbed tunicate *Styela clava* (Ashton 2006) and the black-striped mussel *Mytilopsis* spp. (Willan et al. 2000).

A study on commercial fishing vessels and recreational vessels (displacement and trailered) identified seven vessel components that can be infected with NIS (Hayes 2002a): 1) hull, 2) deck, 3) internal spaces 4) fishing gear, 5) propeller, 6) rudder and 7) anchor. These components were subsequently divided into subcomponents (e.g. keel and exhaust outlet on the hull), identifying the way(s) they could become infected (i.e. their *infection mode*) (see Appendix A). A total of eight infection modes were identified: 1) external fouling (visible when vessel is either in or out the water), 2) internal fouling (hidden from view), 3) borer (organisms that bore into wooden or fibreglass surfaces), 4) refuge (harbours an organism *visible to the naked eye*), 5) retained water (water retained when vessel is either in or out the water), 6) retained sediment (sediment retained when vessel is either in or out the water), 7) catch parasites (catch infected with non-indigenous parasites) and 8) bait (bait or parasites on the bait are NIS).

1.3. Fault Tree Analysis as a modelling tool in the marine invasion processes.

Fault tree analysis is a common technique used in engineering for formalising conceptual models (Ayyub 2001, Burgman 2005). Fault trees have been largely used in safety and diagnostic studies (e.g. failure of engines) and in the designing of new products and services (e.g. software and hardware design) (Andrews and Moss 2002). Fault trees have been also used in the ecology area. For example, they were used to assess the decline of lizard populations and the failure of Blackbox and River Red Gum stands to regenerate in Victoria, Australia (Carey et al. 2004). The IUCN protocol used to assess the risk of extinction of species is based on a fault tree analysis (IUCN 1994, 2001). However, the applicability of this technique in the modelling of marine invasions has been somehow limited, with only a few examples dealing with NIS introductions via ballast water (Hayes and Hewitt 1999, Hayes and Hewitt 2000, Hayes 2002b) and via recreational vessels (Acosta and Forrest 2009). The ballast water fault trees identified the combinations of events that could lead to an incursion in a recipient port when ballast water is discharged. Similarly, the fault trees presented by Acosta and Forrest (2009) identified the combination of events that could lead to an incursion when an infected recreational vessel (i.e. vessel with a NIS) was visiting an infection-free environment.

1.4. Fault Tree Analysis Methodology

Fault Tree Analysis is a technique that graphically analyses the system from the top to bottom, identifying the occurrence of an event (the *top event*) as the result of the occurrence or non-occurrence of other (intermediate) events. *Intermediate* events are also described further until the *basic* or *undeveloped* events are identified. *Basic* events require no further development because an appropriate level of resolution has been reached. *Undeveloped* events required no further development because information is unavailable or because its consequences are insignificant. Using the logic functions *OR* and *AND*, a fault tree analysis represents graphically all the parallel and sequential combinations of events that could make the *top event* occur. A list of the symbols commonly used in fault tree analysis is provided in Figure 1a.

Intermediate events have only one input which can be a basic event, an undeveloped event or a logic gate (OR or AND). Logic gates can have any number of inputs. These inputs can be intermediate, basic events and/or undeveloped events. The resulting event of an OR gates occurs if one or more of the inputs occur. The resulting event of an AND gate occurs only if all the input events occur.

1.5. Fault tree analysis example

The following figure (Figure 1b) and fragment extracted from the article published by Hayes (2002,b) is a good example of the sequential approach used when developing a fault tree analysis.

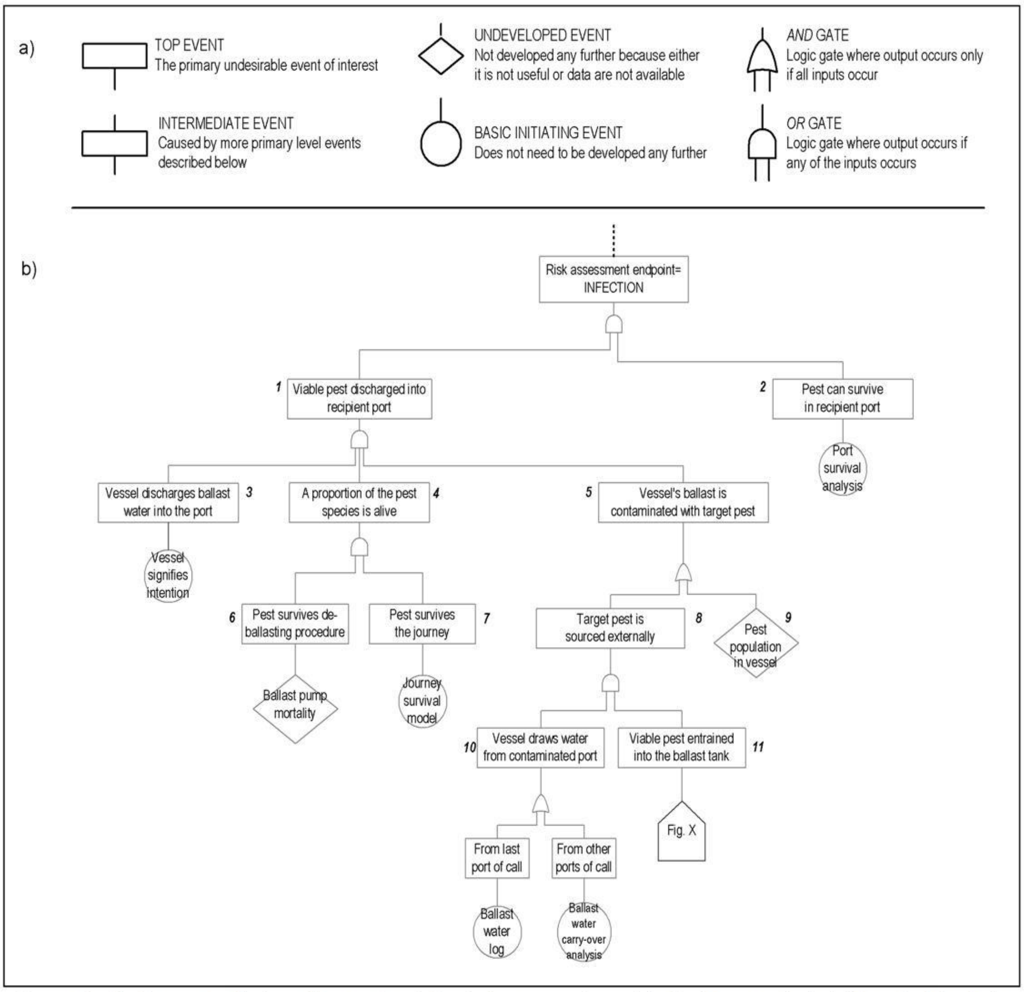

Figure 1. Fault tree symbols and example. a) Symbols commonly used in Fault tree analysis. b) Part 1 of the fault-tree developed for ballast-water introductions. The top event is successful infection of the recipient port, defined here as

the introduction of a non-indigenous species (the target pest) into a port where it can survive. This part shows all necessary events between entrainment of a viable organism in the ballast tank and infection of the recipient port (from Hayes 2002,b).

Hayes (2002b) describes the fault tree presented in Figure 1b as follows: "…The top event in this instance is successful infection of a recipient port. Successful infection of the recipient port (a port that receives ballast-water from a vessel) occurs if:
• a viable (i.e. alive) organism is discharged into the recipient port (1); AND,
• the organism is capable of surviving in the port (2).
The probability that the organism will survive in the port is an undeveloped event. This can be calculated by comparing, for example, the temperature and salinity characteristics of the port with the temperature and salinity tolerances of the species concerned…Three events must occur for a viable organism to be discharged into a recipient port:
• the vessel must discharge its ballast-water into the port (3); AND,
• some proportion of the target species in the ballast water must be alive (4); AND,
• the vessel's ballast-water must be contaminated with the target species (5).
There is no need to develop the first event further –the vessel either does or does not need to deballast and can signify its intention accordingly….For an organism to be alive when discharged from a ballast-tank, it must:
• survive the deballasting procedure (6); AND
• survive the vessel's journey (7).
The effect of ballast pumps on the subsequent survival of organisms has not been sufficiently well researched to develop it further in the fault-tree….Journey survival is not developed further in the fault-tree because it can be explicitly modelled…"

2. INSTRUCTIONS FOR ANALYSING AND MODIFYING THE MODEL

This section gives some instructions on how to analyse and make the changes to the model presented in section 3.

2.1. Instructions

Please read the following instructions in order to make your changes to the fault trees.

1- Read and analyse the conceptual model provided in this section thoroughly. Remember that definitions and assumptions are essential parts of the model so please consider them during your analysis.

2- Make all the changes you think are required in order to make the model more comprehensive and realistic.
   a. If you consider that the model does not need any changes, please indicate so.
   b. You can add, delete or modify any of the definitions, assumptions, components, events and relationships.
   c. You do not need to justify your changes but if you are able to provide an example and/or reference relevant to your change(s), please do so.

If there is **ANYTHING** in the model, (e.g. terms, components, relationships between events) that you do not understand, please contact me for further explanations.

Please **do not discuss the model with anybody else**. This could affect your perception of the problem and interpretation of the model, and thus, your answers.

2.2. How to make changes to the model

As mentioned before you can either make your changes directly on this document or print out a hard copy of the document and make the changes on it.

2.2.1. Changes on this electronic copy

I do not mind which method you use, as long as I can identify and understand ***the changes you have made.***

If you are going to make the changes directly on this electronic copy, you might want to use the following options:

Adding Comments and/or Changing Definitions and Assumptions: You can type your changes directly on this word document. You are welcome to use a different font colour for your changes. It is fine however, if you want to use the original font colour (i.e. **black**) as your changes could be tracked using the "Track changes" option from *Microsoft Word*.

Changing a Fault Tree:

- ***Describe your changes using the numbers of the events***

The events of the fault trees presented here are identified with two numbers. The first number represents the number of the figure (or fault tree) while the second number represents the event in that particular figure. For example, the event labelled *3.12* represents the event number 12 presented in figure 3.

Therefore, you can describe in words your changes at the end of the document by indicating the number of the event and the type of change you want to make (e.g. modify, delete, add, move). You can also add any comments, examples or references at the end of each change. For example:

- If you want to add a basic event under event 3.12 (i.e. figure 3 event 12), you could write:

"Add - Basic event to Event 3.12 and label it "Weather conditions", comment= weather is a determining factor for vessel V to visit that area.

- If you want to delete events 3.12 and 3.27 (i.e. events 12 and 27 in figure 3), you could write:

"Delete – Events 3.12 and 3.27, comment= These are not relevant to the occurrence of event 3.8.

- ***Using an alternative option***

If you do not want to use any of the above mentioned options and have another method to make your changes, please feel free to use it.

2.2.2. Changes on a hard copy

If you are going to print a hard copy of the document and make the changes directly on that copy you might want to use one the following options:

- ***Modify and Post***

Mark your changes on the hard copy and post this to the address provided. You can add any comments, examples or references at the end of each figure. Please use figure and event numbers, so that I know where your change, comment, reference or example is relevant.

- ***Modify and Scan***

Mark your changes on the hard copy and scan it to your computer. Once the document has been scanned you can email it. Please use figure and event numbers so that I know where your change, comment, reference or example is relevant.

- ***Using an alternative method***

If you do not want to use any of the above mentioned options and have another method to make your changes, please feel free to use it.

3. CONCEPTUAL MODEL

The model here presented is an updated version of the model published by Acosta and Forrest (2009). As stated at the beginning of the exercise the objective is to use your knowledge to improve this model.

3.1. The process modelled

The model represents the introduction process of a NIS into an area via recreational vessels. In order to make visualisation of the process easier, an incursion scenario has been described as followed:

Vessel V, a recreational vessel, can travel from Area Y to Area Z. Species S is present in Area Y but it has never been present in Area Z

3.2. Modelling technique, vessel components and infection modes

The incursion process of Area Z has been modelled using the Fault tree analysis technique. The development of the model of Acosta and Forrest (2009) began considering all the vessel components and infection modes suggested by Hayes (2002a). This initial model however, was cumbersome and had a high level of redundancy. For this reason, the authors modified or combined some of the vessel components and infection modes. For example, components Hull, Rudder and Propeller were analysed as a single component (i.e. Hull) as all of them are permanently underwater and hence subject to similar conditions. As some recreational vessels are likely to be used also for SCUBA-diving, diving gear was included in the Fishing Gear component. Due to the similarities of the process for the release of a NIS from External fouling, Internal fouling, Refuge and Borer, these four infection modes were grouped under the single category Fouling. Similarly, Water retention and Sediment retention were grouped under Water/Sediment retention. The final components and infection modes used in the model are presented in the following table (Table 1).

Table 1. Vessel components and infection modes used for the Fault Tree analysis.

Vessel component	Infection mode	Examples
Hull, propeller and rudder (Hull)	Fouling	Propeller surfaces
Deck	Water/sediment retention	Hawser pipe
	Fouling	Cracks between plates
Internal spaces	Water/sediment retention	Bilge
(including ballast tanks)	Fouling	Seawater inlet/outlet
Anchor	Water/sediment retention	Rope, anchor well
	Fouling	Anchor surface
Fishing gear	Water/sediment retention	Trap ropes, diving bag
(including diving gear)	Fouling	Dredges
Trailer	Water/sediment retention	Hollow sections of chassis
	Fouling	Mudguards

3.3. Definitions and Assumptions

The model uses the following definitions and assumptions:

- **Assumptions**

1. Cruising patterns of Vessel S area known.
2. User of Vessel S does not take any specific control measures to prevent entrainment of Species S in Area Y, and further transport of it to Area Z.
3. When Vessel V is in Area Z, it may or may not have contact with marine structures (e.g. marinas, wharves, boat ramps).
4. Vessel V has 6 different components that can be infected by Species S: 1)Hull (including propeller and rudder), 2) Deck, 3) Internal Spaces, 4) Anchor 5) Fishing Gear (including Diving gear) and 6) Trailer (see Table 1).
5. If Species S can tolerate certain environmental conditions then its propagules can tolerate similar conditions.

- **Definitions**

Automatic discharges occur without the intervention of the user of the vessel. They are carried out by pumps equipped with float switchers and/or sensors (e.g. automatic bilge pumps).

Cleaning habits covers all the information about the cleaning of the vessel. It includes information about the components and subcomponents that are cleaned (e.g. hull, gunwale and bilges), how often these components and subcomponents are cleaned and the cleaning method used (e.g. scraping, water blasting, scrubbing). It also covers user-conducted cleaning and commercially-conducted cleaning.

Discharge is the release of any element, liquid or solid, organic or inorganic, from a boat into the sea. Although discharge may be part of a cleaning process, discharge by itself is not considered as cleaning.

Disturbances refers to changes in the physicochemical and hydrodynamic characteristics of the environment considered (e.g. temperature, salinity, exposure to water drag). These changes are abrupt and do not represent the natural variation of these characteristics (e.g. daily, seasonal). They are usually generated by external components of the environment considered (e.g. turbulence in the bilge of a yacht generated by storm weather).

Environmental Data is any measurements or information on biological, physicochemical and hydrodynamic processes that describe a location (e.g. a bay, a marina or the bilge in a yacht). Environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as databases or the literature.
Fouling is defined as accumulation of both visible and not visible organisms. It includes organisms that are not able to attach themselves to the structures but either get entangled or are able to live in/on the vessel component. Some of these organisms may be mobile (e.g. crabs and starfish) and live amongst the other fouling organisms.
Infection location identifies the exact place on the vessel component where the NIS is present (e.g. exhaust outlet).
Infection mode identifies how marine organisms inhabit the vessel's components.
Recreational boating is the activity related to the use of recreational vessels (e.g. keelers, motor cruisers, small powered crafts). This can include sailing, cruising, recreational fishing and racing, among others.
Release of propagules is the release of any structure with the capacity to give rise to a new organism (e.g. spawn, fertilised eggs, juveniles, body fragments with regeneration ability).
Scrape is to make a surface smooth or clean with strokes of an instrument or an abrasive.
Scrub is the act of cleaning a surface by rubbing it with a brush.
Species behaviour identifies the way species usually behave under specific environmental conditions. Species behaviour is directly determined by the characteristics of the species.
Species characteristics includes the biological and ecological characteristics of the species. The characteristics of a species will determine its tolerance to physicochemical conditions of the environment as well as its mobility.
Trailer is the a nonautomotive vehicle designed for transporting a boat and to be hauled by road
User awareness refers to the vessel user's knowledge on the problem of marine invasions in general, and species S in particular.
User-controlled discharges only occur when the user of the vessel carries them out or initiates them (e.g. turning on the bilge pump, removing a drain plug).
Vessel activity defines the activity the owner is conducting with the vessels at a specific time. This includes cruising, mooring, anchoring, fishing, diving and drifting, as well as cleaning.
Water and Sediment retained is the accumulation of water or sediment in a vessel component
Weather conditions identify the state of the weather at a given time and place, with respect to variables such as temperature and wind velocity and direction.

3.4. The model and fault trees

The model described below identifies the main events that must take place for an incursion of Specie S to occur in Area Z as a result of Vessel V visiting this area (Figure 2). Although the model develops the intermediate event "Arrive in Area Z" further, its main focus is on the release process (Figures 3-9).

Notes:

- Remember that events **are referenced by the number of the figure and the number of the event in that figure**.
- Events are cited in the text using this unique reference number. For example, "Vessel visits Area Y (2.12)" means that this event is located in figure 2 and referenced with number 12 (i.e. 2.12)
- All the figures of the model have been attached at the end of this document.

INFECTION OF AREA Z (Figure 2)

The top event of the analysis, in this case "Area Z becomes infected with Species S" (2.1), only occurs if all the following events occur (Figure 2):

- Species S arrives in Area Z (2.2) in/on Vessel V; AND
- Species S is released in Area Z from Vessel V (2.3); AND
- Species S survives in Area Z (2.4).

Arriving in Area Z (Figure 2)

Two intermediate events must occur if an organism of Species S is to arrive in Area Z on Vessel V:

- Vessel V arrives in Area Z (2.5); AND
- Vessel V is infected with Species S from Area Y (2.6).

The arrival of Vessel S in Area Z can be determined by the vessel's cruising habits (2.7) so there is no need to develop this event further. For Vessel V to be infected with Species S the following two events must occur:

- Vessel V becomes infected with Species S in Area Y (2.8); AND
- Species S survives the trip from Area Y to Area Z (2.9).

The trip survival of Species S depends on the interaction of several factors such as species characteristics, environmental conditions of the infected part and characteristics of the trip (e.g. length). It is then necessary to develop specific survival models for each of the potentially infected components of the vessel (2.10).

Vessel V becomes infected with Species S in Area Y only if:
- Vessel V has contact with Area Y (2.12); AND
- Species S is entrained by Vessel V (2.11);

Vessel V has contact with Area Y (2.11) because either:
- Vessel V is based (moored or launched) in Area Y (2.13); OR
- Vessel V visits Area Y (14)

These two events are determined by Vessel V's cruising habits (2.15, 2.16). Whether Species S is entrained by vessel V in Area Y is determined by the interaction of several factors (e.g. species characteristics, vessel activity). Therefore, entrainment models for each vessel component must be developed to analyse this risk (2.17).

Release in Area Z (2.3)
As any of the six components of Vessel V could be infected, each component is analysed as a potential source of Species S. Thus, release of Species S may occur from any of the following components:
- Hull, (2.18); OR,
- Deck (2.19); OR
- Internal Spaces (2.20); OR
- Anchor (2.21); OR
- Fishing Gear (2.22); OR
- Trailer (2.23)

Survival in Area Z (2.4)
A specific model has to be developed to estimate the likelihood of survival of Species S in Area Z. This model must be based on the biology and ecology of the species and the environmental characteristics of Area Z (2.24).

RELEASE IN AREA Z (Figures 3-8)

Hull (hull, rudder and propeller) (Figure 3)
Fouling is the only infection mode considered for the Hull component. If Species S is present in Vessel V as fouling (3.1), two events can lead to its release into the environment: the release of propagules (3.2); OR the release of organisms (3.3).

The release of propagules can occur naturally (3.4) OR be induced by disturbances (3.5). Information on the life cycle of Species S (3.6) and environmental data of Area Z (3.7) (e.g. temperature, salinity) can be used to estimate the likelihood of natural release of propagules. Release of propagules can be also induced by disturbances (3.5). Determining this event requires information on the type of disturbances that can occur in Area Z and the type of disturbances that can lead Species S to release propagules. Hence knowledge of the biological and behavioural characteristics of Species S is also required (3.8).

Organisms can be released into the water forcibly (3.9) OR voluntarily (3.10). Whether organisms leave the hull voluntarily is determined by mobility and behaviour of Species S under certain environmental conditions (3.11). Organisms can be forcibly (deliberately or accidentally) dislodged into the environment by cleaning (3.12), OR predation (3.13), OR scraping (3.14), OR water drag (3.15).

Dislodgement by cleaning (3.12) can be the result of user-conducted cleaning (3.16) OR commercial-conducted cleaning (3.17). Whether these events dislodge organisms is determined by cleaning habits (3.18, 3.19), infection location (3.20, 3.21) and user (3.22) or cleaner (3.23) awareness. Infection location in the model refers specifically to vessel component's area where the NIS is present. Dislodgment by predation is determined by the presence of organisms that feed on the fouling community (3.24).

Organisms can be dislodged by scraping when the Hull has contact with other structures in Area Z (3.25). The structures that the Hull can have contact with are: berthing, mooring and boat ramp structures (3.26), other boats (3.27), the sea bottom and beach (3.28), fishing gear (3.29), the anchor (3.30), and the trailer (3.31). Whether there is contact with these structures, and this contact scrapes organisms into the environment, is determined by the activity of the vessel (3.32 - 3.37) and the infection location (3.38 - 3.43). In order to determine whether water drag dislodges organisms (3.15), it is necessary to identify the infection location (3.44), the hydrodynamic forces that work on it and the force required to dislodge the species. All of this information can be used to develop a dislodgment model (3.45).

Deck (Figure 4)

Two infection modes are considered for Deck: water/sediment retention (4.1) and fouling (4.2).

If the component Deck is infected with water or sediment (i.e. organisms or propagules of Species S may be present), this retained water/sediment can be released into the environment (4.3) by: Natural forces (4.4); OR Anthropogenic forces (4.5); OR Accident (4.6). Three events, described here as Wind (4.7); OR Rain (4.8); OR Waves (4.9) can lead to the release of Species S into the water by natural forces via water/sediment retained. Whether these events occur is determined by the infection location (4.10 - 4.12) and weather conditions (4.13 - 4.15). Anthropogenic forces refers to the discharge of retained water/sediment by the user (4.16). The infection location (4.17), cleaning habits (4.18) and user awareness (4.19) determine whether this event leads to the release of Species S into the environment. Accident (4.6) encompasses all of the events that lead Vessel V to sink (4.20).

If Species S is present in the Deck as fouling, the same two events as described for Hull (Fig. 3) can release it into the environment: organisms are released (4.21); OR propagules are released (4.22). Similarly, organisms can be released into the water forcibly (4.23) OR voluntarily (4.24). Forcible release in this case could include accidents (4.27) in addition to natural (4.25) or anthropogenic (4.26) forces. In the same way as for the water/sediment retained infection mode, the release of fouling organisms into the environment by natural forces can be the result of wind, rain or waves (4.28 - 4.30). As for Hull, infection location (4.31 - 4.33) and weather conditions (4.34 - 4.36) determine whether these events occur. The release of organisms by anthropogenic forces (4.26) and accident (4.27) can be modelled with the same series of events used for these components in the water/sediment retained infection mode (4.37 - 4.41). Organisms can also be released into the environment when they voluntarily leave the location of the infection (4.42), as described for the Hull component.

For the fouling infection mode, the event "Propagules are released" (4.22) occurs only if Species S produces propagules (4.44) AND these propagules reach the water (4.45). The propagule production of Species S can be modelled based on the same events and factors (4.46 - 4.50) identified for the release of propagules in the Hull. However, in the Deck component whether propagules reach the water is determined by the location of the infection (4.51).

Internal spaces (Figure 5)

The component Internal spaces refers to spaces such as sea/gray-water inlet-outlets, bilge (open and closed), storage rooms, anchor well, holding tanks (including ballast tanks), pumps, toilet/shower and wheelhouse, among others (Hayes 2002a). Two infection modes are considered for Internal spaces: water/sediment retention (5.1) and fouling (5.2).

If Species S is present in the water/sediment retained, two events could release it into the environment (5.3): discharge from Internal spaces (5.4); OR cleaning of Internal spaces (5.5). Discharge of water/sediment from Internal spaces can occur automatically (5.6) or manually (5.7). The factors that determine whether Species S is released by an automatic discharge process are infection location (5.8), weather conditions (5.9) and vessel activity (5.10). Similarly, the factors that determine the release of Species S by a user-controlled discharge are infection location (5.11), weather conditions (5.12), vessel activity (5.13) and user awareness (5.14). Whether the cleaning of Internal spaces(5.5) results in the release of Species S into the water is determined by the infection location (5.15), cleaning habits (5.16) and user awareness (5.17).

If Species S is present in the Internal spaces as fouling (5.2), it could be released into the environment in the same way as described for components Hull and Deck, (i.e. as organisms, fragments or propagules). Organisms are released because either the discharge process dislodges them into the water (5.20) OR the user releases them during cleaning activities (5.21). The first event occurs only if there is discharge of the internal space (5.22) AND if this discharge dislodges Species S (5.23). As with the retained water/sediment, discharge of Internal spaces can be automatic (5.24) or user-controlled (5.25), with similar lower events also applying (5.26 – 5.32). Note that, in order to determine whether the discharge process dislodges Species S (5.23), it is necessary to have an understanding of the force required to dislodge the species, and the mechanical and hydrodynamic forces that work on the infected space (5.33). The release of organisms by the user during cleaning (5.21) is determined by the infection location, (5.34), cleaning habits (5.35) and user awareness (5.36).

Propagules are released into the water only if Species S releases propagules in the internal space (5.37) AND there is discharge from that space into the environment (5.38). Whether there is a discharge of the internal space is determined by the same factors mentioned above (5.39 - 5.40). The event "Propagules are released in internal spaces" (5.37) can be modelled by the same events and factors (5.48 - 5.51) considered for the release of propagules in the Hull component; however, in this occasion the environment considered is the internal space and not Area Z.

Anchor (Figure 6)
Two infection modes are considered for the anchor: water/sediment retention (6.1) and fouling (6.2). Retained water/sediment can be released on the deck (6.3) OR directly into the environment (6.4). When the retained water is release on the deck, the release model (6.5) will be the same fault tree depicted in Figure 4. Retained water/sediment can be released directly into the environment (6.3) when the anchor is deployed (6.6) OR when it is cleaned (6.7). If the anchor is deployed depends on vessel activity (6.8). Whether the retained water/sediment is released to the environment during cleaning depends on cleaning habitats (6.9) and user awareness (6.10).

If the anchor is infected by fouling, the occurrence of at least one of two events can release Species S into the environment: organisms are released (6.11); OR propagules are released (6.12). Organisms can be released on the deck (6.13), and the release model for this component (6.14) will be the same presented in Figure 4, OR directly into the environment (6.15). Direct release into the environment can occur when the anchor is deployed (6.16) OR cleaned (6.17). The first of these events only occurs if the anchor is deployed (6.18) AND the organisms are dislodged (6.19). Whether the anchor is deployed depends on vessel activity (6.20). Organisms can be dislodged by scraping (6.21) OR by water drag (6.22). Scraping of the anchor can occur as a result of contact with the seabed (6.23). Whether the seabed dislodges Species S by scraping depends on the infection location (6.24) and bottom type (6.25). In order to determine whether water drag dislodges Species S, it is necessary to know the force required to dislodge organisms and the hydrodynamic forces encountered when the anchor is deployed (6.26).

As with organisms, propagules can be release on the deck (6.27) OR directly into the environment (6.28). If released on the deck, the release model (6.29) will be the same described in Figure 4. For propagules to be discharged directly into the environment the anchor has to be deployed (6.30) AND propagules have to be released (6.31). The deployment of the anchor is defined by the activity of the vessel (6.32). The release of the propagules from the anchor, which can be naturally (6.33) or induced by disturbances (6.34) can be modelled by the same events and factors identified for these events in components Hull and Internal spaces (6.35 - 6.37).

Fishing/diving gear (Figure 7)
The infection modes, events and factors considered for the Fishing gear (7.1 - 7.44) are the same as considered for the Anchor component in Figure 6, with infection modes being water/sediment retained and fouling. The main difference with the Anchor component is that the release of fouling organisms or fragments directly into the environment from fishing gear (7.14), is divided into forcibly (7.16) and voluntarily (7.17). Forcible release is modelled by the same events and factors identified for the release of organisms in the case of Anchor (7.18 - 7.31). Whether organisms leave the fishing gear component voluntarily (7.17) on the other hand, is determined by the infection location (7.32), the species characteristics, mobility and behaviour, and the environmental conditions (7.33).

Trailer (Figure 8)

Two infection modes are considered for the component Trailer: water/sediment retention (8.1) and fouling (8.2). If Species S is present in the water/sediment retained, two events could release it into the environment (8.3): the trailer is used to retrieve the Vessel V (8.4) or the trailer is clean at the beach or boat ramp in Area Z (8.5). Whether Species S is released when the trailer is used (8.4) is determined by the infection location (8.6) and user awareness (8.7). Similarly, cleaning habits (8.8) and user awareness (8.9) will determine whether Species S is released during cleaning (8.5).

If the trailer is infected by fouling (8.2) the occurrence of at least one of two events can release Species S into the environment: organisms are released (8.10); OR propagules are released (8.11). Two events can release organisms into the environment (8.10): the trailer is used to retrieve Vessel V (8.12); OR the trailer is cleaned in Area Z (8.13). For organisms to be released when using the trailer two events must occur: the trailer is used (8.14) AND organisms are dislodged (8.15). Whether the trailer is used can be determined by the activity of the Vessel (8.16).

Organisms can be dislodged by scraping (8.17); OR by water drag (8.18). Scraping can occur as the result of contact of the trailer with either the beach (8.19); OR the boat ramp (8.20); OR the hull of Vessel V (8.21). Whether this contact causes dislodgment of the organisms is determined by user awareness (8.22 - 8.24) and infection location (8.25 – 8.27). In order to determine whether water drag dislodges Species S (8.18), it is necessary to know the force required to dislodge organisms and the hydrodynamic forces encountered when the trailer is used (8.28).

The release of organisms when the trailer is cleaned (8.13) will be determined by the cleaning habits (8.29) and user awareness (8.30). Whether propagules are released into the environment (8.11) can be modelled by the same processes and events described for components Anchor and Fishing/diving gear (8.31 - 8.38), and could occur be naturally (8.34) or induced by disturbances (8.35).

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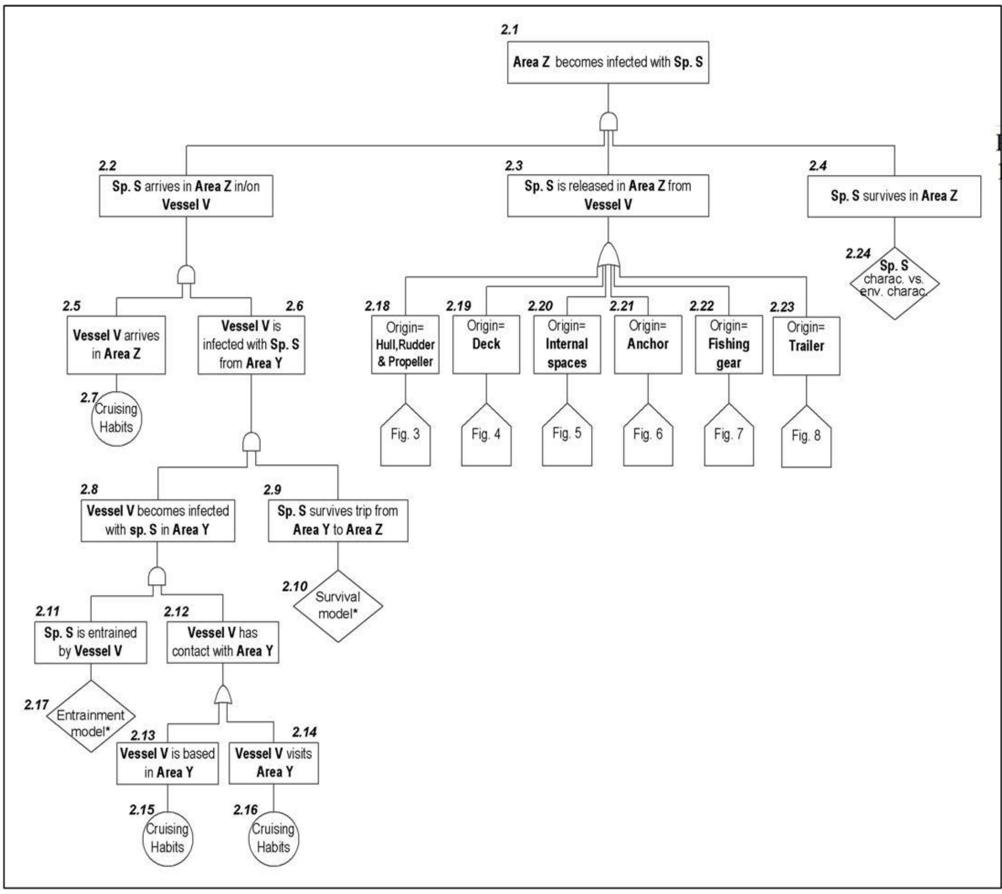

Figure 2. First part of the fault tree developed for the marine invasion process via recreational vessels. The top event is the infection of Area Z. The figure shows the sequence of events from the infection of the Vessel V in Area Y to the release and survival of Species S in Area Z. (*The survival model has to be specific for each vessel component).

Marine invasions and recreational boating – Exercise 1

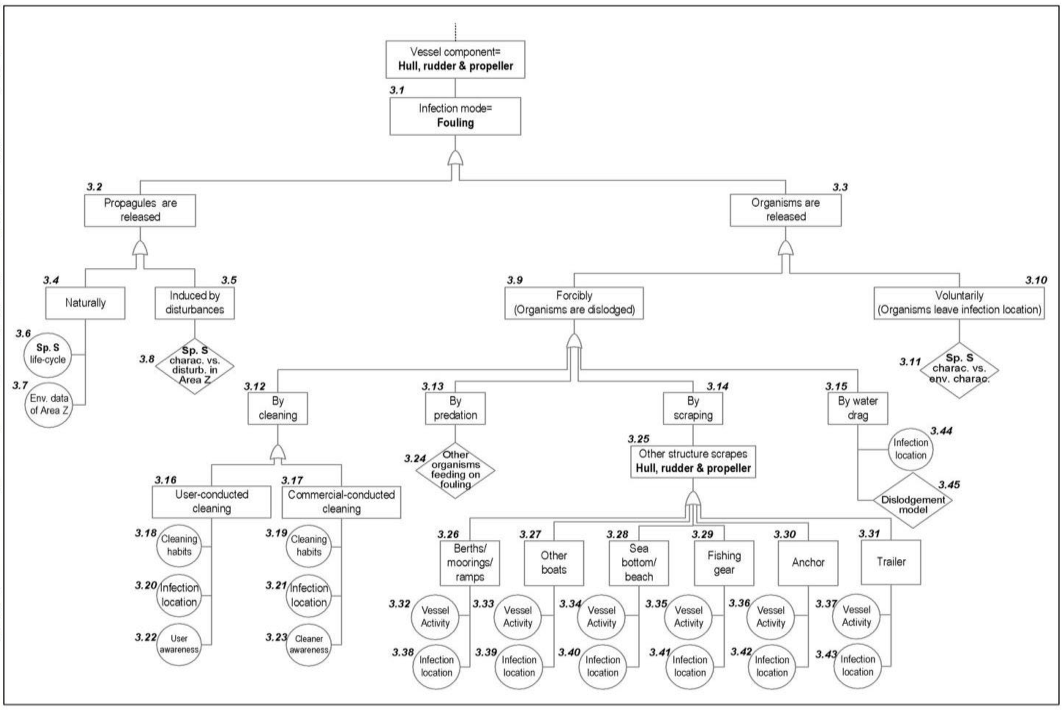

Figure 3. Release of Species S from the Hull, rudder and propeller component (Hull component). Events and combination of events that could lead to the release of the species into the environment if the Hull component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

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Marine invasions and recreational boating – Exercise 1

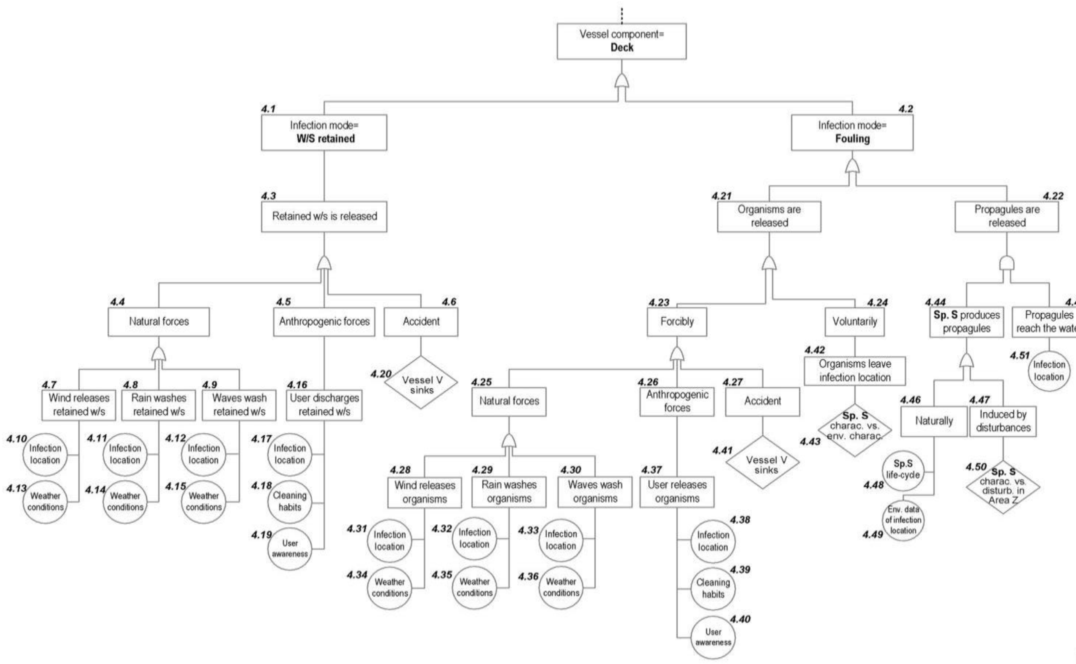

Figure 4. Release of Species S from the Deck component. Events and combination of events that could lead to the release of the species into the environment if the Deck component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

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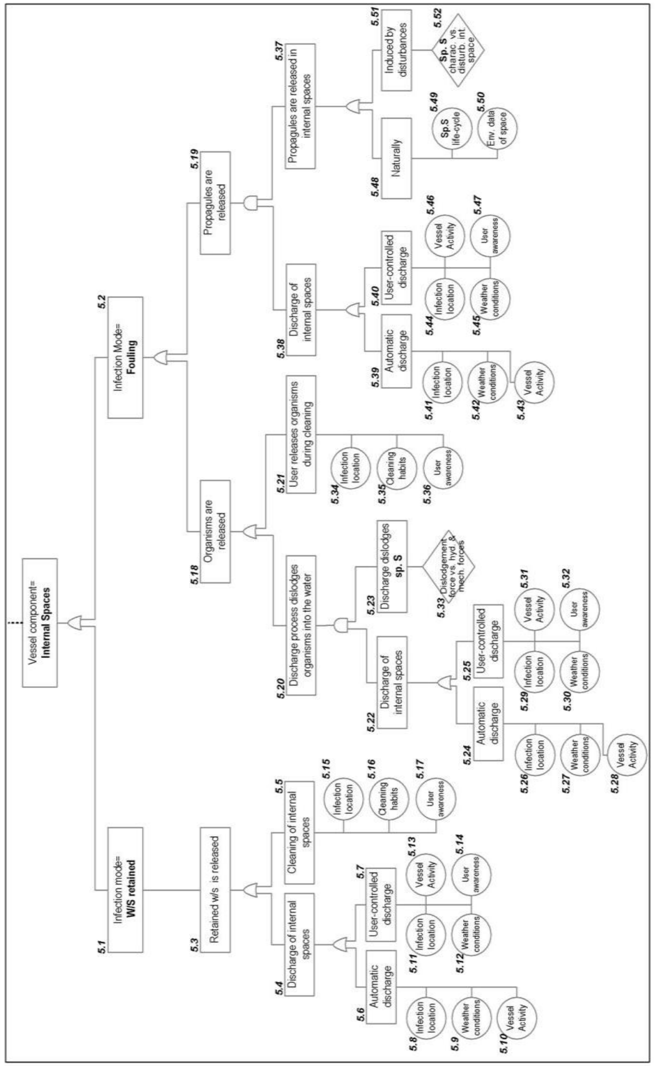

Figure 5. Release of Species S from the component Internal spaces. Events and combination of events that could lead to the release of the species into the environment if the Internal spaces component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

Marine invasions and recreational boating – Exercise 1

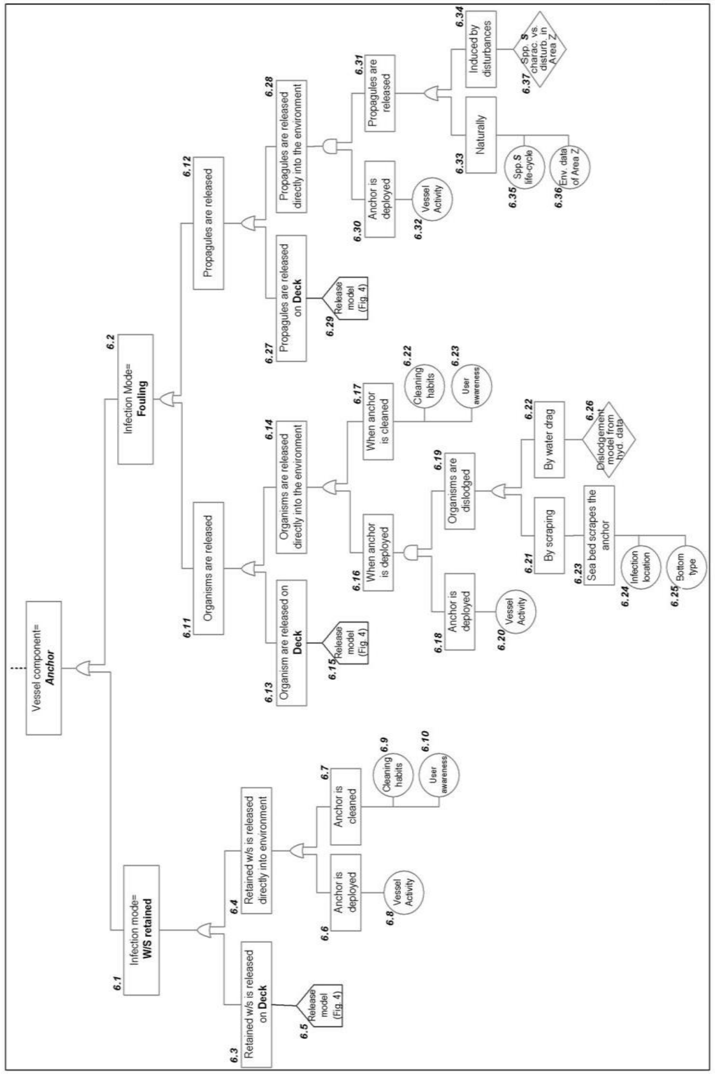

Figure 6. Release of Species S from the component Anchor. Events and combination of events that could lead to the release of the species into the environment if the Anchor component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

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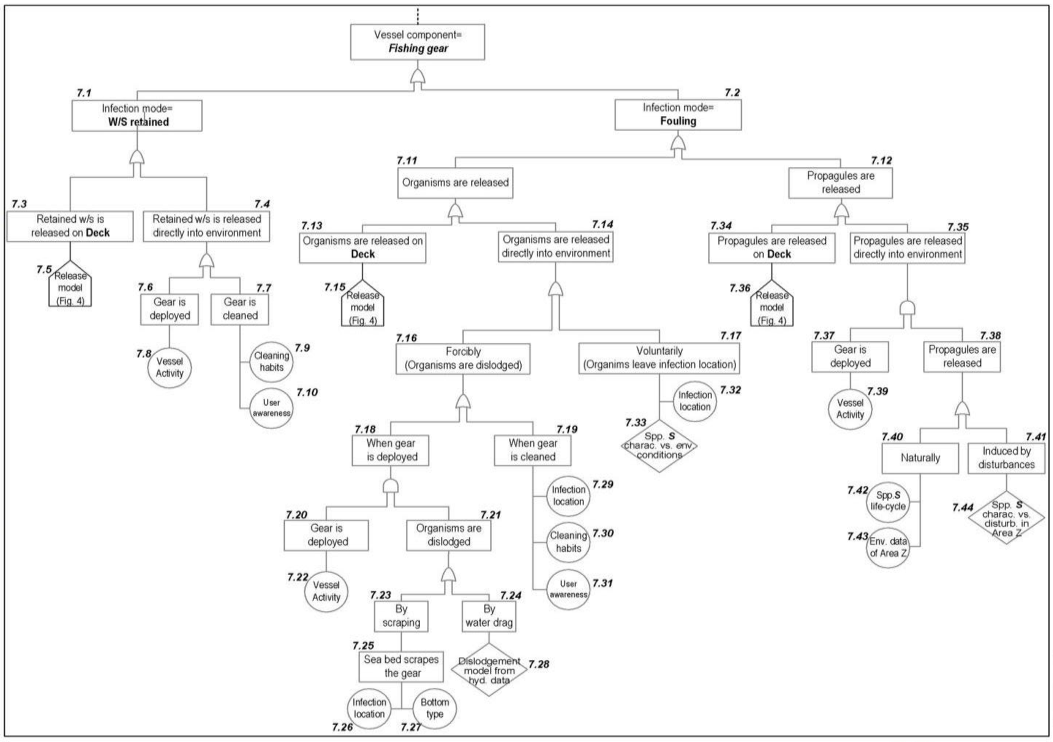

Figure 7. Release of Species S from the component Fishing/diving gear. Events and combination of events that could lead to the release of the species into the environment if the Fishing/diving gear component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

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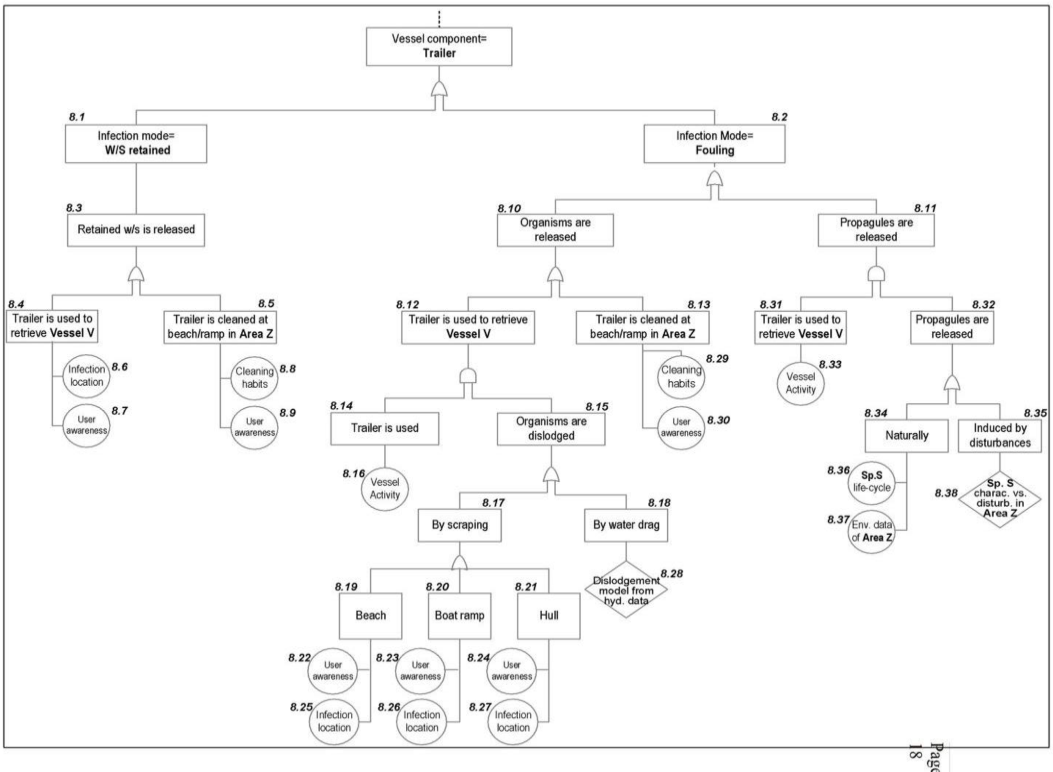

Figure 8. Release of Species S from the component Trailer. Events and combination of events that could lead to the release of the species into the environment if the Trailer component is infected. (charac. = characteristics, disturb. = disturbances, env. = environmental).

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Expert Panel on Marine Invasions – Exercise 1 – Background of experts

BACKGROUND INFORMATION

The aim of this last section is to collect information on the education and work background of the experts.

Please answer the following questions by filling out the empty spaces (i.e. ____).

1. The highest degree I have obtained is (e.g. BSc in Chemistry)
2. I currently work for (e.g. Ministry of Health) in ____ (e.g. Auckland, New Zealand).
3. My position in this agency is (e.g. Analyst, Spatial Analysis Group) ____
4. I have been working in this agency for about (e.g. 4 years) ____
5. Please fill out the following table indicating which of the listed fields you have experience or knowledge on, and how long you have worked on each one. Also indicate the number of scientific publications and reports you have on each of these areas. Write "**NOEX"** to indicate "*NO EXPERIENCE"* in a particular field.

Field	**How long have you worked in this field? (e.g. 6 months, 3 years)**	**How many articles of this field have you published in *Professional Science Journals*?**	**How many articles/reports of this field have you published as grey literature (*Not peer reviewed material*)**	**Is your current work related to this field? (Yes – No)**
Marine biology				
Marine invasions				
Freshwater invasions				
Terrestrial invasions				
Risk assessment				

6. Do you have experience in recreational boating? (select all that apply)

☐ No

☐ Yes...because: ☐ I have been a recreational vessel user for about (e.g. 2 years)

☐ I have to use such vessels as part of my work

☐ I have worked on the risk of vessels as NIS vectors for about (e.g. 6 months)

☐ other: (Please indicate)

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

A.3 SECOND ELICITATION EXERCISE–EXPERT PANEL 2

SECTION ONE – SECOND ELICITATION EXERCISE OF THE PANEL ON MARINE INVASIONS

Dear ***Expert***,

This is the **second (and last)** exercise of the Expert Panel on Marine Invasions. Following there is a description of the objectives and methodology of the exercise. Please do not hesitate to contact me if you have any questions about it.

Objectives
This exercise has two specific objectives:

1. to review the updated version of the model presented in the first exercise
2. to estimate the likelihood of **the release** of a non-indigenous species into a new area from a recreational vessel

Methodology
To complete this exercise please follow these steps:

1. review the updated model and make any changes you considered necessary (section 1)
2. read the baseline information provided in section 2 (this document) which is **essential** for the exercise
3. answer the questions provided (section 3, document "questionnaire_2nd_exercise.doc")
4. email your answers to me.

Please remember to:

1. consider all the assumptions and definitions during the exercise
2. not discuss with anybody this exercise as this could influence your answers

Baseline Information
This information is comprised of two parts:

1. the conceptual model you helped improve in the first exercise
2. a brief description of the recreational boating pathway for a particular region

Answers
To answer the questions just write on the blank spaces or select the appropriate answer from the options provided. Please **do not** answer the questions before you have read the baseline information.

Date of return
I would appreciate if you return your answers before *Date* (i.e. in one week time). I will send you a reminder on *September 21.*

Thanks for your participation in this panel.

Regards,

Hernando Acosta

1

SECTION ONE – SECOND ELICITATION EXERCISE OF THE PANEL ON MARINE INVASIONS

1. CONCEPTUAL MODEL FOR THE MARINE INVASION PROCESS VIA RECREATIONAL VESSELS

Based on the changes, suggestions and comments of the experts during the first exercise, the invasion model has been modified. The model below shows the updated version of this model. Changes have been highlighted in yellow so they can be easily identified.

Definitions, assumptions and fault tree diagrams have been provided but for simplicity the description of the diagrams has been omitted as the fault trees are self-explanatory. Also, most of the events have been described in the first exercise. However, if you need further explanations for any of the events, please do not hesitate to contact me.

1.1. Vessel components and Infection modes

The vessel components and infection modes are the same used in the first exercise (Table 1).

Table 1. Vessel components and infection modes used for the Fault Tree analysis.

Vessel component	Infection mode	Examples
Hull, propeller and rudder (Hull)	Fouling	Propeller surfaces
Deck	Water/sediment retention	Hawser pipe
	Fouling	Cracks between plates
Internal spaces	Water/sediment retention	Bilge
(including ballast tanks)	Fouling	Seawater inlet/outlet
Anchor, rope and chain	Water/sediment retention	Rope, anchor well
	Fouling	Anchor surface
Fishing gear	Water/sediment retention	Trap ropes, diving bag
(including diving gear)	Fouling	Dredges
Trailer	Water/sediment retention	Grooves
	Fouling	Rims

1.2. Definitions and Assumptions

- **Assumptions**

1. Cruising patterns of Vessel V area known.
2. User of Vessel V does not take any specific control measures to prevent entrainment of Species S in Area Y, and further transport of it to Area Z.
3. When Vessel V is in Area Z, it may or may not have contact with marine structures (e.g. marinas, wharves, boat ramps).
4. Vessel V has 6 different components that can be infected by Species S: 1)Hull (including propeller and rudder), 2) Deck, 3) Internal Spaces, 4) Anchor 5) Fishing Gear (including Diving gear) and 6) Trailer (see Table 1).

- **Definitions**

Automatic discharges occur without the intervention of the user of the vessel. They are carried out by pumps equipped with float switchers and/or sensors (e.g. automatic bilge pumps).
Cleaning habits covers all the information about the cleaning of the vessel. It includes information about the components and subcomponents that are cleaned (e.g. hull, gunwale and bilges), how often these components and subcomponents are cleaned and the cleaning method used (e.g. scraping, water blasting, scrubbing). It also covers user-conducted cleaning and commercially-conducted cleaning. The latter is usually conducted in a haul out facility.
Cruising habits refers to the general movement pattern of a vessel.

2

SECTION ONE – SECOND ELICITATION EXERCISE OF THE PANEL ON MARINE INVASIONS

Discharge is the release of any element, liquid or solid, organic or inorganic, from a boat into the sea. Although discharge may be part of a cleaning process, discharge by itself is not considered as cleaning.
Disturbances refers to changes in the physicochemical and hydrodynamic characteristics of the environment considered (e.g. temperature, salinity, exposure to water drag). These changes are abrupt and do not represent the natural variation of these characteristics (e.g. daily, seasonal). They are usually generated by external components of the environment considered (e.g. turbulence in the bilge of a yacht generated by storm weather).
Environmental Data is any measurements or information on biological, physicochemical and hydrodynamic processes that describe a location (e.g. a bay, a marina or the bilge in a yacht). Environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as databases or the literature.
Fouling is defined as accumulation of both visible and not visible organisms. It includes organisms that are not able to attach themselves to the structures but either get entangled or are able to live in/on the vessel component. Some of these organisms may be mobile (e.g. crabs and starfish) and live amongst the other fouling organisms.
Infection location identifies the exact place on the vessel component where the NIS is present (e.g. exhaust outlet).
Infection mode identifies how marine organisms infect/associate themselves with the vessel's components.
Recreational boating is the activity related to the use of recreational vessels (e.g. keelers, motor cruisers, small powered crafts). This can include sailing, cruising, recreational fishing and racing, among others.
Release of propagules is the release of any structure with the capacity to give rise to a new organism (e.g. spawn, fertilised eggs, juveniles, body fragments with regeneration ability).
Scrape to remove (an outer layer, for example) from a surface by forceful strokes of an edged or rough instrument.
Scrub is the act of cleaning a surface by rubbing it with a brush.
Species behaviour identifies the way species usually behave under specific environmental conditions. Species behaviour is directly determined by the characteristics of the species.
Species characteristics includes the biological and ecological characteristics of the species. The characteristics of a species will determine its tolerance to physicochemical conditions of the environment as well as its mobility.
Trailer is the a nonautomotive vehicle designed for transporting a boat and to be hauled by road
User awareness refers to the vessel user's knowledge on the problem of marine invasions in general, and species S in particular.
User-controlled discharges only occur when the user of the vessel carries them out or initiates them (e.g. turning on the bilge pump, removing a drain plug).
Vessel activity defines the activity the owner is conducting with the vessel at a specific time. This includes cruising, mooring, anchoring, fishing, diving and drifting, as well as cleaning.
Water and Sediment retained is the accumulation of water or sediment in a vessel component
Weather conditions identify the state of the weather at a given time and place, with respect to variables such as temperature and wind velocity and direction.

1.3. Fault trees

The following is the summary of the main changes suggested.
Figure 2. -Vessels V could get infected with species S without visiting Area Y (e.g., via infected fishing or SCUBA diving gear, by mooring near a vessel that became infected in Area Y). (2.8, 2.10, 2.11).
Figure 3. "Body/Gear of SCUBA diver" (3.27) has been included under "By scraping" as contact of this component with the hull may dislodge species S. "Weather condition" has been included as a basic event as this could have an effect on the type and frequency of contact between the hull and other structures. "By predation" has been changed for "By other organisms" (3.13, 3.24).
Figure 4. "Vessel sinks" has been changed to "Vessel capsizes or sinks" (4.20). "Birds release organisms" (4.32) has been included under "natural forces".
Figure 5. "Vessel capsizes or sinks" (5.4, 5.26) has been included as a potential mechanism for the release of both w/s retained and fouling.
Figure 6. "Vessel capsizes or sinks" (6.6, 6.9, 6.16, 6.19) has been included as a potential mechanism for the release of both w/s retained and fouling. "Organism leaves infection location" (6.23) has been included as a potential mechanism for the release of species S.
Figure 7. "Vessel capsizes or sinks" (7.6, 7.9, 7.18, 7.21) has been included as a potential mechanism for the release of both w/s retained and fouling.
Figure 8.Scraping by contact with the user (8.20, 8.24, 8.28) has been considered as a mechanism for the dislodgement of Species S. Similarly, "Organisms leave infection location" (8.19, 8.33, 8.34) has been included in the fault tree.

Pages 4–10 of this exercise are not included here as they are just the updated version of the model presented in Appendix A.2. All these were described in the previous page on section 1.3 Fault trees and the final model presented in Chapter 2 includes these changes too.

1.4. CHANGES TO THE MODEL

Please make all the changes you think are required in order to make the model more comprehensive and realistic. Do not forget that:

- If you consider that the model does not need any changes, you have to indicate so.
- You can add, delete or modify any of the definitions, assumptions, components, events and relationships.
- You do not need to justify your changes but if you are able to provide an example and/or reference relevant to your change(s), please do so.

2. RECREATIONAL BOATING PATHWAY IN AREAS Y AND Z

The main components of the recreational boating pathway in the Areas Y and Z could be divided into: 1) recreational vessels (including the trailer) and 2) marine facilities.

2.1. Recreational vessels

Recreational vessels can be divided into **moored** vessels and **trailered** vessels. Moored vessels are kept permanently in the water (>80% of the year), even when they are not in use. They are mainly keelers, launches, multi hulls and motor cruisers. Trailered vessels are kept out of the water on trailers and launched into the water at boat ramps and beaches only when they are going to be used. They are mainly trailer yachts, dinghies and small powered craft.

Recreational vessels in Areas Y and Z are mainly used for cruising, fishing, transportation, diving and racing. It is common for a vessel to visit different locations (e.g. bays, anchorages) during cruising and fishing trips. Fishing gear among vessels is basically limited to fishing rods, dredges, handlines, nets, pots, traps and spearguns.

2.2. Marine facilities

There are seven marine facilities present in Area Y and Z that are usually visited/used by recreational vessels: 1) wharves/jetties, 2) anchorages, 3) moorings, 4) boat ramps, 5) slipways, 6) marinas, and 7) marine farms. Although anchorages in Areas Y and Z do not have artificial structures (e.g. pontoons, buoys, anchors) and thus, would not be marine facilities *per se*, they are included under this category as they are locations frequently visited by recreational vessels.

The marine facilities considered for Areas Y and Z can be described based on the following six characteristics:

a) Location: Where this facility is usually located (e.g. inlets)
b) Visiting vessels: Type of vessels (i.e. moored or trailered) that visit/use the facility
c) Activities: Main activities conducted by users of recreational vessels when visiting/using the facility
d) Visiting time: Consecutive time (e.g. hours, weeks) spent by the vessels at the facility
e) Tidal exposure: Whether the structure/location is intertidal or subtidal
f) Contact type: Frequent types of contact that a recreational vessel can undergo when visiting the facility

Wharves/Jetties are fixed platforms, commonly on wooden or concrete pilings, built parallel to and alongside the shoreline. A wharf/jetty permits vessels to come alongside in a reasonable depth of water to load and unload.

a) Location: Sheltered bays and inlets.
b) Visiting vessels: Moored and trailered vessels.
c) Activities: Vessels moor at wharves/jetties only temporarily, mainly for load and unload. Some users however, may also secure their vessel to this structure while:
- repairing and fitting the vessel
- cleaning the vessel (hull, deck, internal spaces, anchor and fishing/diving gear).

d) Visiting time: Several hours.
e) Tidal exposure: Wharves/jetties may experience tidal desiccation.
f) Contact type: The side of visiting vessels always has contact with wharves/jetties' mooring structures (e.g. wooden pilings). If the area of this structure is exposed to tidal desiccation, the hull of the vessels can also have

contact with the seabed during low tide periods. However, this situation is uncommon as skippers would usually leave the wharf before the tide is out to prevent damage to the vessel.

Anchorages are areas identified by navigation charts, cruising books and vessel users as good places for recreational vessels to lie at anchor. These areas are sheltered and their seabed provides a suitable substrate for the anchor to hold.

a) Location: Bays and inlets protected from prevailing winds and high sea waves.
b) Visiting vessels: Moored and trailered vessels
c) Activities: Anchorages are mainly used as stopovers during cruising trips. Some anchorages are also used for:
- snorkelling/diving,
- fishing, and
- cleaning the vessel (hull, deck, internal spaces, anchor and fishing/diving gear).

Although most of the users only clean the hull above waterline in these areas, a few users also clean the hull below waterline.
d) Visiting time: Between hours to several days.
e) Tidal exposure: Anchorage can be intertidal or subtidal.
f) Contact types: Vessels secured by the anchor are still allowed to swing freely around the anchor with the movement of tides and currents. Sometimes when the anchor is being retrieved, it can have contact with the hull. Depending on the tidal exposure of the anchorage, the hull of the vessels could come into contact with the seabed during low tide, however, this is uncommon.

Moorings are locations where at least one mooring has been set up. A mooring is a structure used to secure recreational vessels. A mooring is formed by a buoy, a rope, a chain and a weight. The buoy is fixed by the rope to the chain that is attached to the weight (usually a block of cement), which is placed in or on the seabed.

a) Location: Sheltered bays and inlets.
b) Visiting vessels: Moored and trailered vessels.
c) Activities: Moorings are essentially used for securing recreational vessels. Depending on the location of the mooring, some users may also conduct the following activities in these areas:
- snorkelling and diving,
- fishing (i.e. fishing rod)
- cleaning the vessel (hull, deck, internal spaces, anchor and fishing/diving gear)

Although most of the users only clean the hull above waterline in these areas, few users also clean the hull below waterline.
d) Visiting time: Most moorings are used for several hours to several days at a time. Some vessels however, are permanently moored in these locations
e) Tidal exposure: Moorings can be intertidal or subtidal.
f) Contact type: The side and hull of the vessel, and sometimes its deck, can have contact with the buoy and rope of moorings. A recreational vessel secured at a mooring is still allowed to move freely around this structure with the movement of tides and currents. If the mooring is in the intertidal area (and experiences tidal desiccation), vessels visiting this location would also have contact with the seabed during low tide.

Marinas are facilities comprehensively designed for the accommodation of vessels. Marinas are usually made of concrete structures, wooden pilings and floating pontoons. They can have berths, swing moorings and pile moorings for securing vessels, as well as anchoring areas.

a) Location: Always located in sheltered inlets.
b) Visiting vessels: Mainly moored vessels although trailered vessels also visit them quite frequently.
c) Activities: Marinas are essentially used as permanent storage locations and temporary stopovers during cruises. Users may also conduct the following activities while the vessel is moored in the marina:
- repairing and fitting the vessel,
- cleaning the vessel (deck, hull, internal spaces, anchor and fishing/diving gear)

Although cleaning activities are allowed in the marina, while the vessels are in the water no discharges contaminated with oils, fuels or effluent are permitted. Vessel must be lifted from the water to a washdown area for hull cleaning and the antifouling cleaning and painting. Some vessels however, are cleaned in the water by divers scrubbing fouling from the hull.

d) Visiting time: Varies with vessel type. Moored vessels spend between few hours to several months. In extreme cases it can be years (e.g. living on board). Trailered vessels usually do not spend more than weeks.
e) Tidal exposure: Some marinas may experience tidal desiccation.
f) Contact type: The side of the vessel can have contact with most of the structures present in the marina. Contact with securing structures (e.g. berths and pole moorings) is usually inevitable, and very likely to be constant during the stay in the marina. If the marina is exposed to tidal desiccation, the hull of the vessel can also have contact with the seabed during low tide periods.

Boat ramps are Inclined concrete ramps that connect a road with the sea, used to launch and retrieve vessels.
a) Location: Reasonably sheltered bays and inlet areas.
b) Visiting vessel: Mainly trailered vessels (< 24 ft). Small moored vessels may use them but this is not common.
c) Activities: Boat ramps are mainly used for launching and retrieving trailered vessels. However, a common practice among vessel users is to clean their vessels at the ramps after cruising or fishing trips (either in the water or out of the water).
d) Visiting time: Several hours.
e) Tidal exposure: All boat ramps are intertidal.
f) Contact type: The hull of trailered vessels usually has contact with the seabed and the trailer during the launching/retrieving process. Sometimes the hull also has contact with the boat ramp during this process.
g) Maintenance: Infrequent. Cleaning and repairing activities are conducted only when required.

Slipways are inclined concrete ramps that extend out into the sea for launching and retrieving vessels. They are usually equipped with a cradle that helps to support the vessels when out of the water.
a) Location: Reasonably sheltered bays and inlet areas.
b) Visiting vessel: Large trailered vessels (>24ft). Moored vessels when they need to be serviced (e.g. antifouling coating, hull repairing).
c) Activities: Slipways are mainly used for launching and retrieving large trailerable and moored vessels. However, a common practice among users of slipways is to clean their vessels in this location after cruising or fishing trips (either in the water or out the water).
d) Visiting time: Few hours to several days.
e) Tidal exposure: All slipways are intertidal.
f) Contact type: The hull of trailered vessels usually has contact with the seabed, the trailer or the cradle during the launching/retrieving process. Sometimes the hull also has contact with the ramp during this process.

Marine farms are collection of fixed and floating structures especially designed for activities of breeding, cultivation, on-growing or harvesting of shellfish; including spat catching and holding. These structures are comprised of submerged concrete blocks, wooden pilings, buoys, ropes, chains, wires and stainless steel frames, among others. Marine farming in Areas Y and Z is primarily focused on mussels.
a) Location: Always located in the subtidal areas in locations usually sheltered from prevailing currents and waves.
b) Vessel type: Moored and trailered vessels.
c) Visiting time: Few hours.
d) Activities: Most of the recreational vessels that visit marine farms are involved in marine farming activities. They visit the farms to inspect the spat, crop and/or structures. They also conduct maintenance and repairing activities in the farm (e.g. cleaning and changing buoys and ropes). These activities might include SCUBA diving. Some recreational vessels however, visit these structures for sightseeing, fishing and/or as part of their cruising routes.
e) Tidal exposure: Marine farms are subtidal.
f) Contact type: The side and hull of a visiting vessel, and sometimes its deck, can have contact with some of the structures present in the farm (e.g. buoys, ropes, wooden floating structures).

NOTE: The side of a recreational vessel can have contact with other vessels when visiting/using any of the structures mentioned above. Also, the rafting up of two or more vessels on one anchor is used sometimes. However, skippers usually avoid this situation as this contact can damage the vessels.

2. QUESTIONNAIRE

2.1. RELEASE OF NIS INTO THE ENVIRONMENT FROM RECREATIONAL VESSELS

The aim of this section is to assess how likely it is for a non-indigenous species (NIS) to be released from a recreational vessel, when this vessel is visiting/using a specific marine facility/area.

In order to answer the questions in this section you must assume that:

1- Vessel V is a recreational vessel
2- Any of the components of Vessel V (i.e., hull, deck, internal spaces, anchor, fishing gear or trailer) could be infected with Species S (a NIS)
3- Vessel V visits/uses the indicated marine facility/area

Each question indicates the type of facility considered and whether you have to assume that vessel V is a moored vessel or a trailered vessel. Similarly, each question indicates whether the facility considered is intertidal (i.e., experience tidal desiccation) or subtidal (i.e., does not experience tidal desiccation). You will indicate **"how likely" you think** the release of species S from vessel V is, when this vessel is visiting the specified facility for each question. You will do this by selecting one of the following four terms:

▪Very unlikely (VU) **▪Unlikely (U)** **▪Likely (L)** **▪Very likely (VL)**

You are to answer each question based on:

1. the release model for recreational vessels (section one),
2. the baseline information on the recreational boating in Areas Y and Z (section two), and
3. your knowledge on recreational boating and marine invasions.

If for a particular question you consider that you are not able to give an estimate, please indicate so by selecting "**Not able**" (**Na**) from the given options.

Please **do not discuss the questions with anybody** unless you have already completed the entire questionnaire.

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Marine invasions and recreational boating - Exercise 2 - Questionnaire

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Question 1.

Please fill out **column 2** ("How likely") in **Table 1.** Select either **Very unlikely** (**VU**), **Unlikely** (**U**), **Likely** (**L**) or **Very likely** (**VL**) to indicate the **likelihood** of Species S being released into the area **vessel V** when this is using/visiting the facility/location listed (column 1). Assume that Vessel V in this instance is a **moored vessel.** If for a particular question you consider that you are not able to give an estimate, please indicate so by selecting **Na** ("not able"). Do **NOT** fill out columns 3 and 4 yet.

Table 1.

MOORED VESSEL											
1	2					3	4				
Facility	How likely					Reason(s)	Updated How likely				
	VU	U	L	VL	Na		VU	U	L	VL	Na
Anchorages – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Anchorage – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Wharves/Jetties – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Wharves/Jetties – Subtidal	☐	☐	☐	☐	☐	MOORED	☐	☐	☐	☐	☐
Mooring – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Mooring – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Boat ramps – Intertidal	☐	☐	☐	☐	☐	VESSEL	☐	☐	☐	☐	☐
Slipways – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marina – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marina – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marine farm – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐

Question 2.

Please fill out **column 2** ("How likely") in **Table 2.** Select either **Very unlikely** (**VU**), **Unlikely** (**U**), **Likely** (**L**) or **Very likely** (**VL**) to indicate the **likelihood** of Species S being released into the area **vessel V** when this is using/visiting the facility/location listed (column 1). Assume that Vessel V in this instance is a **trailered vessel.** If for a particular question you consider that you are not able to give an estimate, please indicate so by selecting **Na** ("not able"). Do **NOT** fill out columns 3 and 4 yet.

Table 2.

TRAILERED VESSEL											
1	2					3	4				
Facility	How likely					Reason(s)	Updated How likely				
	VU	U	L	VL	Na		VU	U	L	VL	Na
Anchorages – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Anchorage – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Wharves/Jetties – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Wharves/Jetties – Subtidal	☐	☐	☐	☐	☐	TRAILERED	☐	☐	☐	☐	☐
Mooring – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Mooring – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Boat ramps – Intertidal	☐	☐	☐	☐	☐	VESSEL	☐	☐	☐	☐	☐
Slipways – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marina – Intertidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marina – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Marine farm – Subtidal	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐

- **Question 3**

Please go back to **Table 1** (**moored vessel**) and **Table 2 (trailered vessel)** and **for each of your answers**:

1. think about one reason that could make your initial likelihood estimation incorrect,
2. write this "reason" in column 3 of the tables, and
3. fill out column 4 ("**Updated How likely**") deciding whether after thinking about this reason you will change your estimation or not.

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3- ASSESSMENT OF TERMS OF LIKELIHOOD

The aim of the following question is to have an idea of what the terms *Very unlikely, Unlikely, Likely* and *Very likely* used in previous questions mean to you.

Please answer the questions below (i.e. write a number in the blank spaces ____) based on the following scenario:

"A man reaches into a bag of 100 golf balls and without looking grabs one"

If some balls are painted blue, you would describe his chances of grabbing a blue one as (see the example below):

a) **Very Unlikely**: if **no more** than of the balls in the bag are blue,
b) **Unlikely**: if **no more** than of the balls in the bag are blue,
c) **Likely**: if **no more** than of the balls in the bag are blue, and
d) **Very Likely**: if **more** than **c)** of the balls in the bag are blue

For example, one might "describe his chances as '**remote**' if no more than ***15*** of the balls in the bag are blue"

This is the end of the questionnaire and the elicitation exercises

Please:

1. **Double check that you have answered ALL the questions,**
2. **Save this document (e.g. second_exercise_"Name".doc), and**
3. **Email this document to me.**

THANK YOU FOR YOUR TIME

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Appendix B: Chapter 3

B.1 GOLDEN BAY AND TASMAN BAY RECREATIONAL VESSEL USER QUESTIONNAIRE

Hernando Acosta
Auckland University of Technology
09- 9179999 ext 8185
hacosta@aut.ac.nz

Dear **vessel owne**r,

I am a PhD student from Auckland University of Technology and my research project is on **marine invaders in the Golden-Tasman Bay area**. Marine invasive species are well known to have environmentally and economically detrimental effects on the invaded areas. Unfortunately, being an area with busy commercial and recreational vessel traffic, the Golden-Tasman Bay region is threatened by the arrival of marine invaders. Therefore, it is essential to develop strategies that prevent the appearance, and further spread, of invasive species within this area.

The general objective of my project is to develop **a risk assessment model** for the Golden-Tasman Bay region, integrating current and potential invasion pathways (e.g. international shipping lines, regional boating routes and aquaculture trade). This model will help scientists, managers and stakeholders (e.g. yacht clubs) to setup realistic and effective marine biosecurity procedures to prevent marine invaders in the region.

As part of the project I need to identify the **number and types of vessels** present in Golden Bay and Tasman Bay. I also need to identify which **areas** are **more frequently visited** throughout the year and determine what kind of maintenance the owners do on their vessels. This is the reason why I am contacting you. Without **your input** in this part, I am unlikely to provide meaningful results which could be valuable to all.

I am sending you **a short questionnaire** (i.e. 2 pages and 2 maps) which will help me collect information on regional vessel traffic in the Golden-Tasman Bay region. Answering the questions will take you no more than 10 minutes. I would really appreciate if you could take this time to answer the questionnaire and post it back to me. A free-post envelop has been provided with the questionnaire. Alternatively you could fax your questionnaire at 09-917 9973.

The information you provide in the questionnaire will be treated **strictly confidentially** and will be only used for the purpose of this research, which has no commercial implications. In addition, as the questionnaire does not ask for any personal information or contact details you can be sure that all your answers will be anonymous. The information of all completed questionnaires will be integrated in a database for analysis and categorisation of vessels and areas visited.

I appreciate your participation and contribution to my research and to the prevention of marine invaders in the Golden-Tasman Bay region. Additionally, if you answer and send the questionnaire back **before June 30**, you will be in the draw for **a fleece jacket up to the value of $200** kindly donated by **KATHMANDU Ltd**. You will also have **4 chances to win a pair of polarised sunglasses** kindly donated by **DIRTYDOG EYEWEAR©**. However, you will have to write your contact details on the back of your envelop. This information will only be used for the draw, and under no circumstances will it be related to your answers. Questionnaires received via fax will also be in the draw. You will need to include a fax cover with your details.

If you have any questions about this project and/or will want to receive a summary of my findings, please do not hesitate to contact me.

Thank you in advance for your collaboration.

Yours sincerely,

Hernando Acosta

PS: If you have more than one vessel, please feel free to photocopy the questionnaire and send them back in the same envelope. If you know somebody who owns a vessel in this region and has not received a questionnaire, please tell them to contact me.

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Please pass this fax onto:
HERNANDO ACOSTA
Earth and Oceanic Research Institute

-MARINE BIOSECURITY PROJECT-VESSELS PRESENT IN THE GOLDEN-TASMAN BAY REGION
Questionnaire

Please select or write your answers in the spaces provided

1. THE VESSEL (Please provide some details on your vessel in the spaces below)

a. Type of vessel:
□ dinghy □ trailer yacht □ keeler □ small powered craft (launched at boat ramps)
□ multi hull □ motor cruiser □ launch □ barge □ other: ____________________

b. Model (e.g. *Laser2000*, *McGregor19*): ____________________________________

c. Length: -Waterline length: _________ meters -Overall length: _________ meters

d. Cruising Speed: ___________ knots

e. This vessel has a sea chest: □ NO □YES…Approximate size of sea chest:__________(e.g. 0.4x0.6m)

f. Does this vessel have a ballast water system?: □ NO □ YES

g. Year built: _____________

h. The vessel is usually (i.e. > 80% of the time) moored at: _________________________

i. The vessel is not moored but my usual launching points are: ________________ ____________

________________________ ________________________ ________________

2. VESSEL USAGE (Please provide some details on the use of your vessel in the spaces below)

a. Please write inside the boxes the average number of days you use your vessel in the Golden-Tasman Bay region during the months indicated? (e.g. MAY [10])

JANUARY [ ] FEBRUARY [ ] MARCH [ ] APRIL [ ] MAY [ ] JUNE [ ] JULY [ ]

AUGUST [ ] SEPTEMBER [ ] OCTOBER [ ] NOVEMBER [ ] DECEMBER [ ]

b. This vessel visits other regions besides the Golden-Tasman Bay region
□ NO □YES …..Which regions? □ Marlborough Sounds
□ Others: _______________ _______________

_________________ _________________ _____________ ___________

c. When in the Golden-Tasman Bay region, this vessel uses/visits the following structures :
□ MARINAS □ MOORING SITES □ BOAT RAMPS □ WHARVES □ JETTIES
□ PORTS □ ANCHORAGES □ SLIPWAYS □ PONTOONS □ MARINE FARMS

d. This vessel is mainly used for (select all that apply):
□ TRANSPORTATION □ RECREATION
□ DIVING □ SCIENTIFIC RESEARCH
□ FISHING □ RACING
□ CHARTER (please also tick the main activity of your clients e.g. fishing, diving)
□ OTHER (please indicate what this one is) :_________________________

1

Please pass this fax onto:
HERNANDO ACOSTA
Earth and Oceanic Research Institute

e. If you selected **FISHING** please answer these 3 questions, otherwise go **Section 3**:

1-Fishing gear used: ☐ FISHING ROD ☐ TRAWLS ☐ POT/TRAP ☐ DREDGE ☐ HAND LINE
☐ NET ☐ LINE ☐ SPEARGUN ☐ OTHER (please indicate which one): ______________

2-Bait used: ☐ LIVE ☐ DEAD ☐ BOTH ☐ NO BAIT IS USED

3-This vessel has live bait wells: ☐ NO ☐ YES…..Are they used? ☐ NO ☐ YES

3. HULL MAINTENANCE (Please provide some details on the maintenance of your vessel in the spaces below)

a. I clean the hull of my vessel (below waterline):

☐ each time I take the boat out of the water after a days sailing

☐ at least: __________________________ (e.g. 1 time every 2 years)

b. I clean the hull of my vessel when it is:

☐ IN THE WATER

☐ OUT THE WATER:... ☐ HAUL-OUT FACILITIES ☐ SLIPWAYS ☐ TIDAL GRIDS ☐ JETTY
☐ BOAT RAMPS ☐ BEACH/ESTUARY ☐ OTHER:____________________

c. I usually clean the hull of my vessel in ___________________________ (e.g. Port Motueka)

d. I will be more likely to clean the hull of my boat in the following month(s):

☐ JANUARY ☐ FEBRUARY ☐ MARCH ☐ APRIL ☐ MAY ☐ JUNE ☐ JULY
☐ AUGUST ☐ SEPTEMBER ☐ OCTOBER ☐ NOVEMBER ☐ DECEMBER ☐ANY MONTH

e. I use antifouling paint for the hull of my vessel: ☐ YES ☐ NO

f. The last time I painted the hull was in ____________________ (e.g. March 1999)

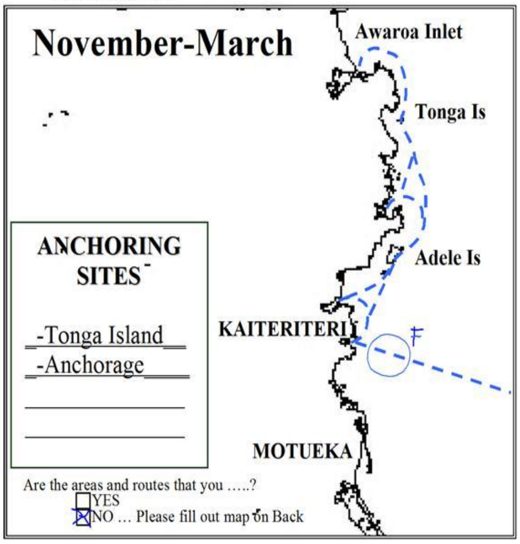
g. Is the sea chest cleaned every time the hull is cleaned? ☐YES ☐NO ☐NON APPLICABLE

h. Do you use any methods to reduce sea-chest fouling? ☐YES ☐NO ☐NON APPLICABLE
Which one?_____________________________________

4. AREAS VISITED (Please provide some information on the areas you visit with your vessel in the spaces below)

Please use the following 2 maps to indicate which areas you are more likely to visit in the Golden-Tasman Bay region during the time periods specified. (i.e. Map 1: **November-March**
Map 2: **April-October**)

EXAMPLE:



Instructions to fill out the maps
(see example provided)

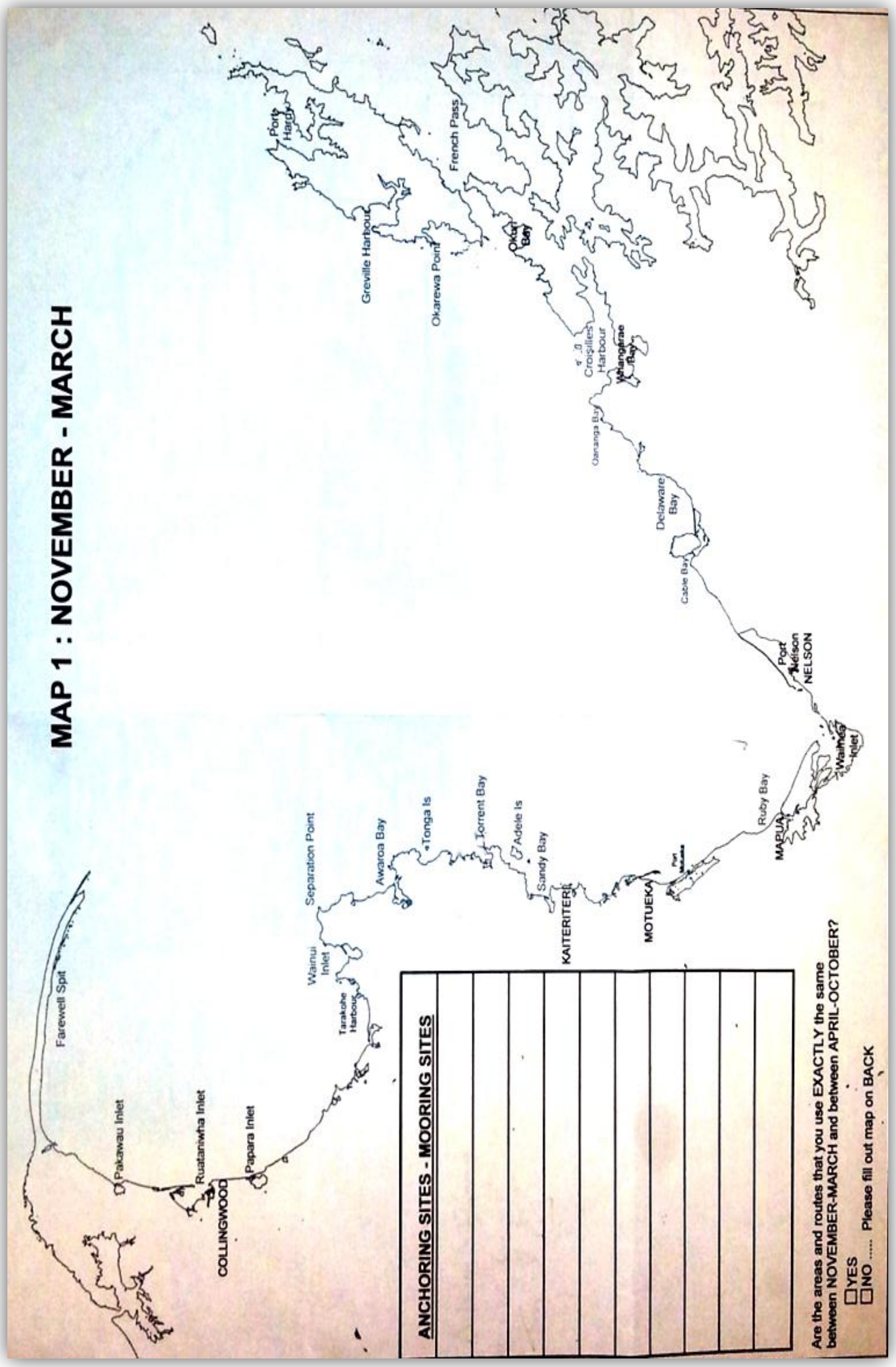
1- Unfold the map and draw the usual routes you follow to get to these areas (please be as specific as possible)

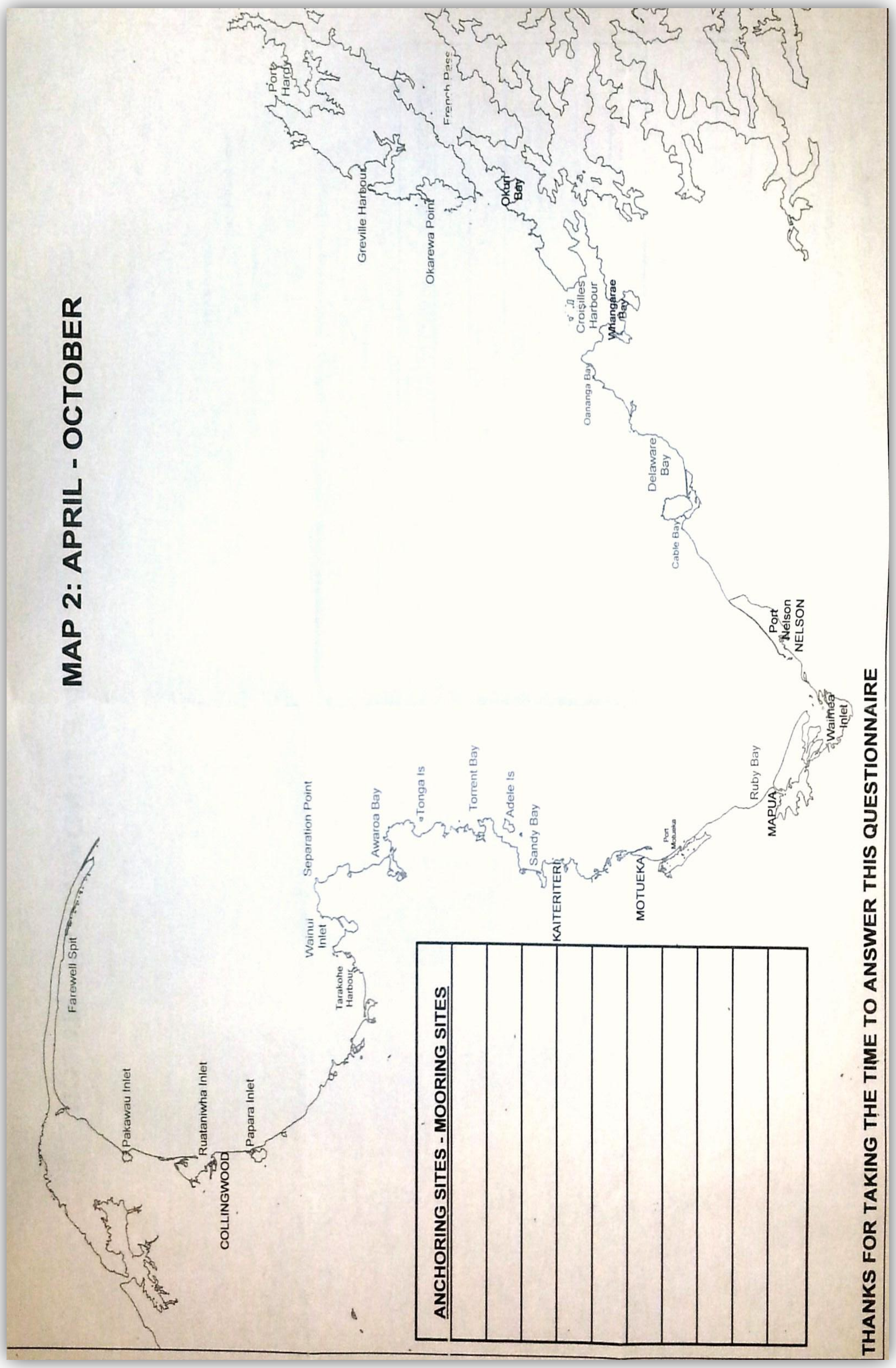
2-Write down the names of the anchoring/mooring sites you use (if any) in the box.

3-Circle those areas that you use for Fishing and/or Diving (if any), identifying them with an F or a D, respectively.

4-If the areas and routes that you use are not **EXACTLY** the same for November-March and for April-October, please fill out **BOTH** Map 1 and Map 2 (Map 2 on back of Map 1).

2


MAP 1 : NOVEMBER - MARCH
Farewell Spit
Pakawau Inlet
Ruataniwha Inlet
COLLINGWOOD
Papara Inlet
Tarakohe Harbour
Wainui Inlet
Separation Point
Awaroa Bay
Tonga Is
Torrent Bay
Adele Is
Sandy Bay
KAITERITERI
MOTUEKA
MAPUA
Ruby Bay
Waimea Inlet
Port Nelson
NELSON
Cable Bay
Delaware Bay
Oananga Bay
Whangarae Bay
Croisilles Harbour
Okarewa Point
Okiwi Bay
Greville Harbour
French Pass
Port Hardy
ANCHORING SITES - MOORING SITES
Are the areas and routes that you use EXACTLY the same between NOVEMBER-MARCH and between APRIL-OCTOBER?
YES
NO ..... Please fill out map on BACK


MAP 2: APRIL - OCTOBER
Farewell Spit
Pakawau Inlet
Ruataniwha Inlet
COLLINGWOOD
Papara Inlet
Tarakohe Harbour
Wainui Inlet
Separation Point
Awaroa Bay
Tonga Is
Torrent Bay
Adele Is
Sandy Bay
KAITERITERI
MOTUEKA
Port Motueka
MAPUA
Ruby Bay
Waimea Inlet
Port Nelson
NELSON
Cable Bay
Delaware Bay
Oananga Bay
Croisilles Harbour
Whangarae Bay
Okuri Bay
Okarewa Point
Greville Harbour
French Pass
Port Hardy
ANCHORING SITES - MOORING SITES
THANKS FOR TAKING THE TIME TO ANSWER THIS QUESTIONNAIRE

B.2 FUZZY LOGIC, INTERVAL TYPE–2 FUZZY SETS (IT2FS) AND FUZZY EXPERT OPINION AVERAGING

B.2.1 Introduction

Expert opinion (also known as expert judgement) is commonly used as a data source and support for system analysis, alternative evaluation and decision-making processes in a wide range of fields such as nuclear power generation (e.g., Ha and Seong 2004, Guimarães and Lapa 2004, Evsukoff et al. 2005, Laes et al. 2008), business and finance (Fildes 2006, Beynon and Peel 2006, Chin et al. 2009, Wu et al. 2009), and occupational health (Azadeh et al. 2008), among many others. There are however, factors associated with expert opinion such as underspecificity and vagueness that can considerably increase the uncertainty present in such approaches (Regan et al. 2002, Burgman 2005). In order to reduce this uncertainty and improve the usefulness of expert data three main aspects need to be considered: 1) the knowledge of experts, 2) the elicitation method, and 3) when more than one expert is considered, the averaging technique (Moon and Kang 1998).

Fuzzy logic (Zadeh 1965) is a technique that can accommodate these three considerations, hence provides a useful approach for dealing with processes (e.g., decision-making) that rely on expert opinion. Fuzzy logic is able to handle data imprecision and provides the additional ability to deal naturally with vagueness of language, a valuable advantage when data are represented through linguistic terms (e.g., likely, high). Fuzzy logic is now commonly used in fields where uncertainties are present such as modelling and control (Bezdek 1993), signal processing (Castro et al. 2009), computer and communication networks (Fadaei and Salahshoor 2008, Tajbakhsh et al. 2009), diagnostic medicine (Toprak and Güler 2008, Schaefer et al. 2009) and finance (Plikynas et al. 2005, Celikyilmaz et al. 2009). Similarly, fuzzy logic is today frequently used as the preferred method for combining and averaging expert opinion (e.g., Yu and Park 2000, Ferreira Guimarães 2003, Fiordaliso and Kunsch 2005, Chang and Wang 2006, Baraldi et al. 2009, Kaufmann et al. 2009, Damigos and Anyfantis 2011, Page et al. 2012, Sattler et al. 2012, Tatari et al. 2012).

To date, most studies applying fuzzy logic to expert opinion have used traditional fuzzy sets (i.e., type–1 fuzzy sets, T1FS), and only recently have interval type–2 fuzzy sets (IT2FS) been recognised as a more suitable approach to modelling expert opinion and linguistic uncertainties (e.g., Mendel 2001, Wu and Tan 2006, Wu and Mendel 2007a).

B.2.2 Fuzzy logic

Fuzzy logic was first introduced by Zadeh (1965) as an alternative to binary logic, where elements can only 'belong' or 'not-belong' to a set. In fuzzy logic on the contrary, elements belong to a set (i.e., fuzzy set) but only to a certain degree defined by a continuous function between a range of values, which is called 'membership function' (MF) (Fig. B.1). This means that if *A* is a fuzzy set and *x* is a relevant object, the proposition '*x* is a member of *A'* does not have to be necessarily either true or false. This proposition might be true (or false) only to certain degree: the degree to which *x* is in fact a member of the set *A.* Membership function can be defined as characteristic functions that encompasses the values assigned to the elements within the range of the universal set. The most commonly used range of values of membership function is the interval [0,1]. In membership functions a larger value denotes higher degrees of set of membership.

Fuzzy sets therefore, provide a more robust and realistic representation of linguistic terms and thus, reality. For example, the World Health Organization (WHO) considers the body mass index[15] (BMI) as the most appropriate measure to assess the health status of people of any age (WHO 1995). People with a BMI between 18.5–30 are considered 'normal' if their BMI is < 25 but 'overweight' if their BMI is ≥ 25 (WHO 2000). Following this classification, a person with a BMI of 24.91 (e.g., 1.7m and 72kg) is considered normal, and a person with a BMI of 25.01 (e.g., 1.7m and 72.3kg) is considered overweight. In reality however, the 0.09 below or 0.01 above the 25 threshold should not make much difference when describing the BMI of either person, and both could be probably considered 'sort of overweight'/'sort of normal'. Fuzzy logic overcomes this kind of problem by creating a continuous transition from normal weight to overweight and assigning degrees of belonging to each category. In this way, each person would belong to a certain degree to the group of normal and to a certain degree to the group of overweight.

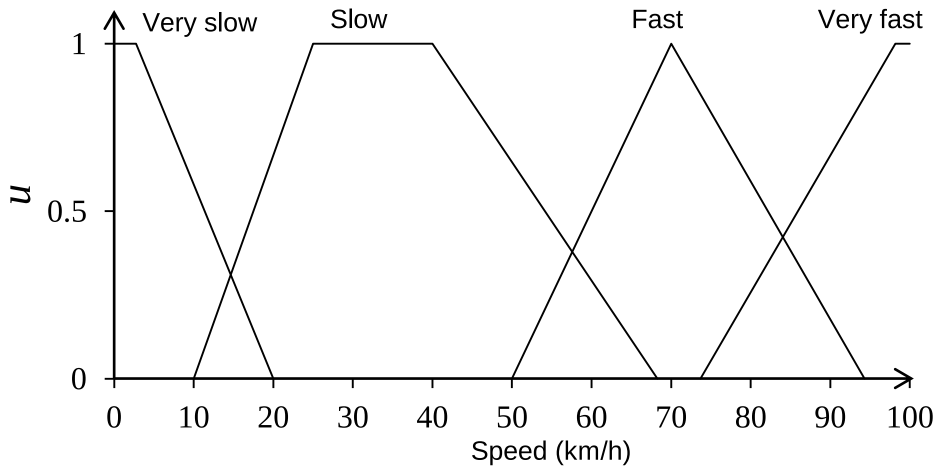


Figure B.1 Examples of interval type–1 fuzzy sets representing descriptive terms of speed. This figure shows illustrative membership functions of the type–1 fuzzy set. μ=degree of membership.

B.2.3 Membership functions, fuzzifier and encoder

A type–1 fuzzy (T1FS) set *A*, commonly refered to simply as a fuzzy set *A,* is comprised of a domain DA of the real numbers and a membership function μ_A: DA [0,1], where for each *x* that belongs to DA the value of $\mu_A(x)$ is the degree of membership, or membership grade, of *x* in *A* (Mendel and Wu 2010). A 'crisp set' *A* could be then seen as a fuzzy set where for each *x* that belongs to DA the degree of membership can only be 1 or 0.

Membership functions were initially conceived to have only crisp values, which limited the grades of memberships to be crisp values (e.g., Fig. B.1). In certain circumstances, as in modelling linguistic terms (Mendel 2007), it is difficult to define an exact MF because of the

[15] This index is calculated as the weight in kilograms of a person divided by his/her height in meters squared.

uncertainty around it. Using crisp values to define a MF in such occasions would simply discard (i.e., ignore) the associated uncertainty, which would be like turning a probabilistic variable into a deterministic one. Zadeh (1975) however, introduced type–2 fuzzy sets (T2FS) characterised by a fuzzy MF (i.e., secondary MF), which means that the membership value (degree of membership) for each element of a T2FS is a T1FS instead of a crisp number (Fig. B.2). This fuzziness of the MF improves the ability of the set to both model and minimise the effect of numerical and linguistic uncertainties. It also avoids the problem of defining an exact MF when this is not a straightforward or valid procedure, as in modelling words (e.g., small, fast, high) (Mendel and Wu 2010).

Although having more design degrees of freedom (parameters) makes T2FS better than T1FS when modelling words, the computational complexity associated with this T2FS approach has usually discouraged people from using it (Mendel 2007). However, interval type–2 fuzzy sets (IT2FSs), a special case of T2FSs defined by Mendel (2001), assume the membership grade for every point of the secondary MF to be 1 (Fig. B.2). Although this reduces its complexity, the essence of the T2FS is preserved and its ability to represent uncertainty is maintained. IT2FSs are usually represented by the footprint of uncertainty (FOU), which is the bounded region defined between the upper MF and the lower MF. These MFs are type–1 functions that represent the maximum (upper MF) and minimum (lower MF) membership grade of the set (Fig. B.2).

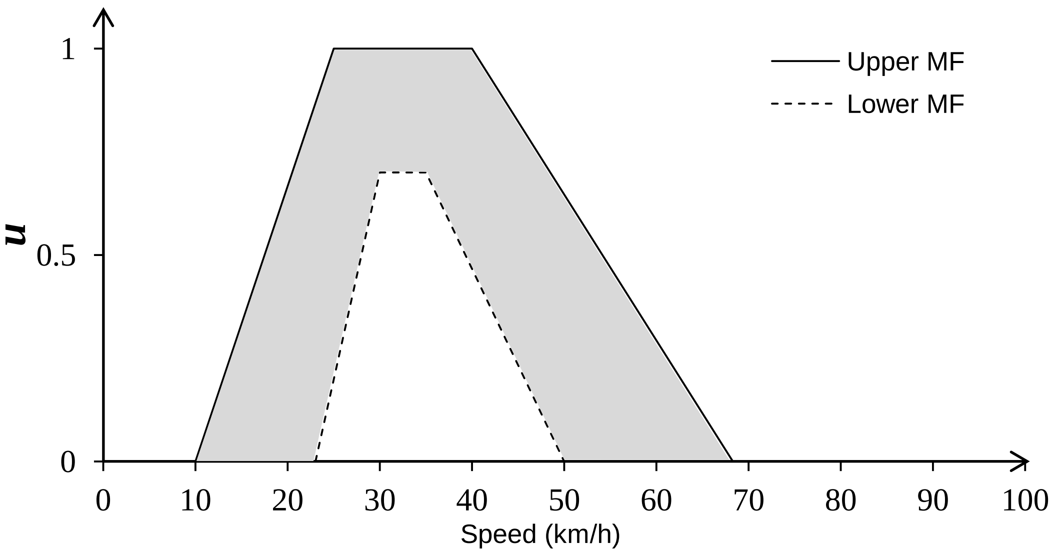


Figure B.2 Example of an interval type–2 fuzzy set representing the term ‘Slow’. Illustrative membership function (MF) of the type–2 fuzzy set. μ=degree of membership. The foot print of uncertainty is defined by the union of the upper MF and the lower MF (gray area).

B.2.4 Perceptual computer

Computing with words (CWW) is defined by Zadeh (1999) as a methodology where the objects of computation are words and propositions drawn from natural language. A CWW for making subjective judgements is usually called a ‘perceptual computer’, Mendel 2001, 2002,

2007) and encompasses three general components: 1) encoder, 2) CWW Engine, and 3) decoder (Fig. B.3).

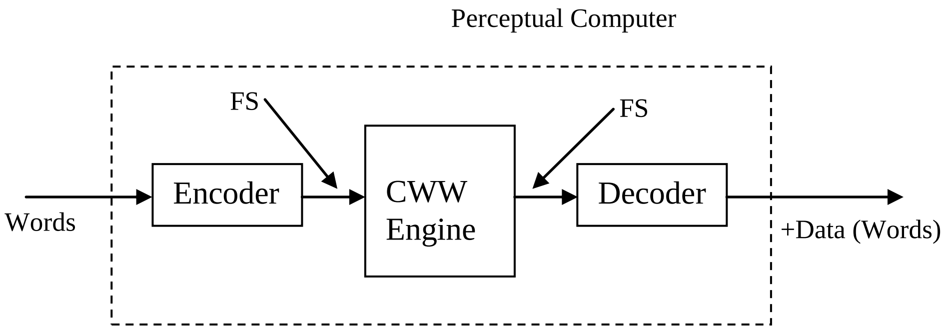


Figure B.3 Architecture for CWW–the perceptual computer (from Mendel and Wu 2010). CCW= Computing with words, FS= Fuzzy set.

The process of combining qualitative expert assessments can be then seen as a perceptual computer. Inputs are entered into the perceptual computer as words that are then encoded using fuzzy sets. The CWW engine processes these inputs and generates the result using fuzzy sets. Such results are then decoded into meaningful data that could be numbers or words (Fig. B2). The perceptual computer can be simple and perform basic operations with fuzzy sets but they can include designs integrating several complex fuzzy logic functions and operations (e.g., Acosta et al. 2010, Wu and Mendel 2010, Wu 2012, Šaletić and Anđelković 2013).

B.2.5 The Perceptual Computer of the thesis

Data collected in Chapter 3 and Chapter 4 were analysed using interval type–2 fuzzy logic. The design of the basic perceptual computer used to combine the expert data (probability assessments) is presented in Figure B.4 and described in the text below. The implementation of the perceptual computer was conducted using the Open–source software QtOctave (http://www.ohloh.net/p/qtoctave).

Expert opinion provided as words needs to be encoded (fuzzified) so computing with words is possible (Mendel and Wu 2010). For this, it is essential to define a membership function for each of the words used. Membership functions are the core of fuzzy logic, hence the way in which they are defined (shape, levels and values) determines the validity of the fuzzy sets represented. Unfortunately, MFs are variable and situation-specific, and although techniques have been suggested to obtain partitions for fuzzy variables (e.g., de Soto and Recasenes 2001), no standard method or rules on how to define their functions is currently available. Some studies, for example, have used the Delphi approach (Dalkey and Helmer 1963) to help experts to generate 'unanimous' MFs (e.g., Kaufman and Gupta 1988). It is possible to say therefore, that MFs are usually created by analysts *ad hoc*, with (Marchini and Marchini 2006) or without (e.g., Raj and Kumar 2001) input from experts.

By obliging experts to either agree on MFs or use previously defined functions, their answers could be less natural and intuitive and, more importantly, the uncertainty originating from different opinions on the meaning of the words would be ignored. Hence, as with Acosta et al. (2010), in order to minimise the interference of the analyst, and maintain and measure this uncertainty through the analysis, the elicitation exercises of Chapter 3 and Chapter 4 required experts to use probability words (e.g., Unlikely, Very likely) naturally (Fig. B.4-1): without getting or providing any information about value ranges for these terms. Only at the end of the exercise, experts were asked to provide their 'believed value range' for each probability word.

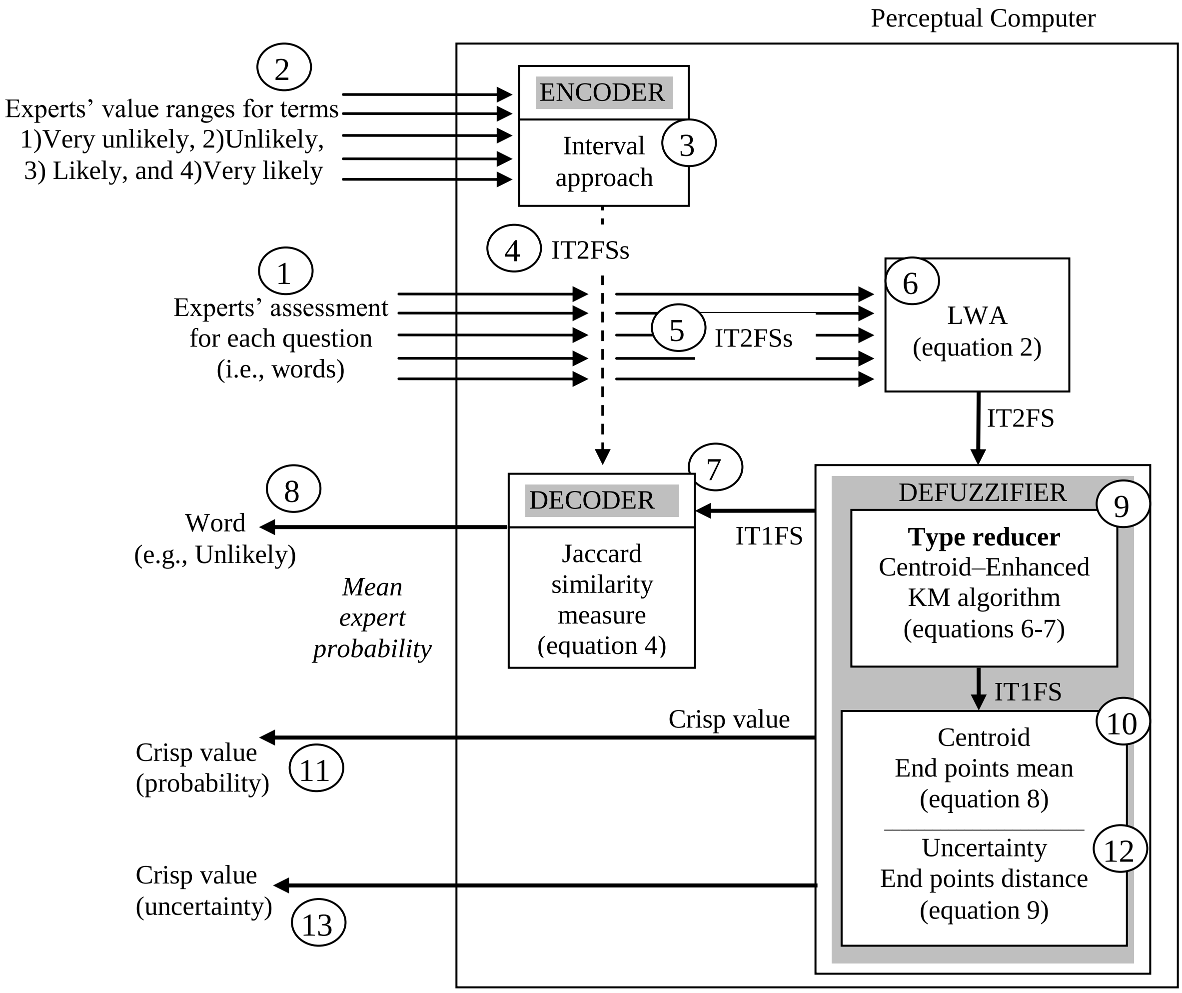


Figure B.4 Perceptual computer used to combine expert opinion. Design of the perceptual computer used to combine the probability assessments provided by experts in Chapter 3 and Chapter 4. LWA: Linguistic weighted average. IT1FS: interval type–1 fuzzy sets, IT2FSs: interval type–2 fuzzy sets.

The ranges given by each expert for each word (Fig. B.4-2) were then integrated using the Interval Approach (Liu and Mendel, 2008) (Fig. B.4-3) to define a representing IT2FS for each word (Fig. B.4-4). This achieved both fuzzification and encoding, made computation of different words possible, and more importantly, incorporated into the analysis the uncertainty from perception differences among experts about word meanings (Mendel 2003).

The original expert answers (Fig. B.4-1) indicated as probability words were replaced with their representing IT2F (Fig. B.4-5) and combined (averaged) using the Linguistic Weighted Average (LWA, Wu and Mendel, 2007a) (Fig. B.4-6). The LWA is defined as:

$$\tilde{Y}_{LWA} = \frac{\sum_{j=1}^{n} w^j \tilde{P}_i^j}{\sum_{j=1}^{n} w^j} \quad \text{Equation B-1}$$

where n is the number of experts, w^j is the weight for expert *j,* and $\tilde{P}_i^j$ represents the word chosen by expert *j*. All experts were considered to be equally important and thus their answers were equally weighted.

A main characteristic and advantage of the perceptual computer is its capacity to present results in a linguistic format so users understand them readily without any particular knowledge of the system (Mendel 2002, 2007, Acosta et al. 2010). The Jaccard similarity measure (Sj) introduced by Wu and Mendel (2009b) was then used to simultaneously defuzzify and decode the resulting $\tilde{Y}$ (i.e., present the result in a linguistic form) (Fig. B.4-7). The Jaccard similarity measure (Sj) for $\tilde{Y}$ and $\tilde{B}$ (both IT2FS) was calculated as (Mendel and Wu 2010):

$$S_j(\tilde{Y}, \tilde{B}) = \frac{\sum_{j=1}^{N} \min(\mu_{\bar{Y}}(x_i), \mu_{\bar{B}}(x_i)) + \sum_{j=1}^{N} \min(\mu_{\underline{Y}}(x_i), \mu_{\underline{B}}(x_i))}{\sum_{j=1}^{N} \max(\mu_{\bar{Y}}(x_i), \mu_{\bar{B}}(x_i)) - \sum_{j=1}^{N} \max(\mu_{\underline{Y}}(x_i), \mu_{\underline{B}}(x_i))} \quad \text{Equation B-2}$$

where N is the number of samples and $\mu_{\bar{P}}$, $\mu_{\bar{B}}$, $\mu_{\underline{P}}$ and $\mu_{\underline{B}}$ are the membership grades of x on the upper and lower MFs of $\tilde{A}$ and $\tilde{B}$, respectively. The Jaccard similarity measure compared the result $\tilde{Y}$ with each of the probability words ($\tilde{B}$), selecting the one with the maximum Jaccard similarity (Mendel and Wu 2010). The combined expert probabilities were then expressed as one of the probabilities used (Fig. B.4-8).

Having a classification system with only four levels simplifies the classification processes and makes broad comparisons possible. This however is likely to limit the differentiating capacity of the system when a large number of scenarios are considered (as in Chapter 3 and 4). Hence, the perceptual computer also calculated the centroid of the combined probability $\tilde{Y}$ (Fig. B.4-9), which defuzzified (translated) the linguistic answer into a crisp value. The centroid of an IT2FS, defined by the characterising left- and right-end points ($[C_l, C_r]$), was calculated as (Mendel and Wu 2010):

$$C_l = \min_{\forall \mu_Y(y_i) \in [\mu_{\underline{Y}}(y_i), \mu_{\bar{Y}}(y_i)]} \frac{\sum_{j=1}^{N} y_i \mu_Y(y_i)}{\sum_{j=1}^{N} \mu_Y(y_i)} \quad \text{Equation B-3}$$

$$C_r = \max_{\forall \mu_Y(y_i) \in [\mu_{\underline{Y}}(y_i), \mu_{\overline{Y}}(y_i)]} \frac{\sum_{j=1}^{N} y_i \mu_Y(y_i)}{\sum_{j=1}^{N} \mu_Y(y_i)} \qquad \text{Equation B-4}$$

where *N* is the number of samples, and $\mu_{\overline{Y}}(y_i)$ and $\mu_{\underline{Y}}(y_i)$ are the membership grades of y_i on the upper and lower MFs of $\tilde{Y}$, respectively. C_l and C_r were computed using the Enhanced Karnik-Mendel algorithm (Wu and Mendel, 2009c) producing an interval T1FS (Fig. B.4-9) that was later defuzzified into a crisp value (Fig. B.4-10). As an interval T1FS is characterised entirely by its left- and right-end points (i.e., C_l and C_r), the defuzzification (i.e., centroid computation) is reduced to simply calculating the mean of these end-points (Mendel 2001). This value therefore represented the actual crisp value of the expert average (Fig. B.4-11):

$$\frac{(C_l + C_r)}{2} = \text{crisp value} \qquad \text{Equation B-5}$$

Several measures such as, cardinality, centroid, fuzziness and variance, have been proposed to estimate the uncertainties, or variability, associated with IT2FS (Wu and Mendel 2007b). However, uncertainty, defined as the distance between the characterizing left– and right–end points (C_l and C_r) of the resulting IT2FS has been identified as the best variability measure when dealing with expert opinion (Wu and Mendel 2009). The perceptual computer therefore, used uncertainty to estimate variability among IT2FSs.

B.2.6 Example

The following example uses the data collected in the second elicitation exercise with the second panel of experts (Chapter 3).

1) Represent probability terms using the lower and upper limits of the 'believed value ranges' given by experts (Table B.1). For illustrative purpose, value ranges are also represented as IT1FS in Figure B.5.

Table B.1 Expert value ranges for linguistic terms used to describe the probability of an event. Data from the second elicitation exercise described in Chapter 3.

	Very unlikely		Unlikely		Likely		Very likely	
Expert	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
1	0	0.1	0.1	0.5	0.5	0.9	0.9	1
2	0	0.01	0.01	0.1	0.1	0.5	0.5	1
3	0	0.05	0.05	0.2	0.2	0.8	0.8	1
4	0	0.05	0.05	0.15	0.15	0.5	0.5	1
5	0	0.1	0.1	0.2	0.2	0.6	0.6	1

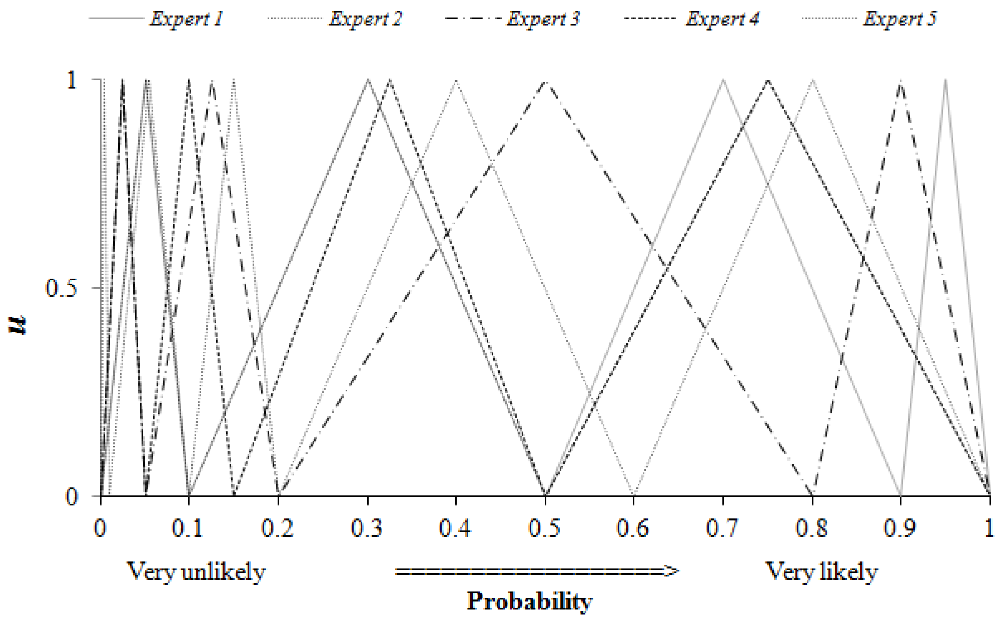


Figure B.5 Interval type–1 fuzzy sets (IT1FS) representing the value ranges given by experts for each of the probability terms used. IT1FS defined based on the assumption that the membership is equal to 1 at the middle of the lower and upper limits. Data from the second elicitation exercise described in Chapter 3. μ= degree of membership.

2) Apply the Interval approach to combine the expert value ranges of each probability term and represent them as an IT2FS (Fig. B.6). .

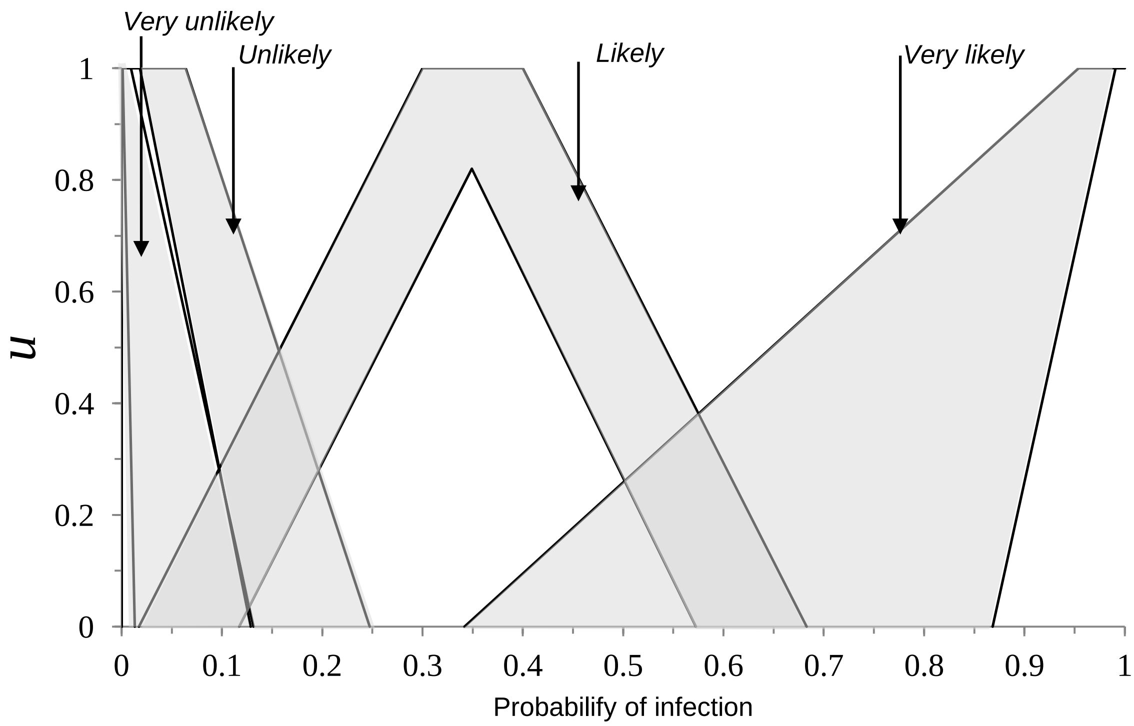


Figure B.6 Interval type–2 fuzzy sets (IT2FS) sets representing each of the terms used by five experts to assess the probability of an event. IT1FS defined based on the assumption that the membership is equal to 1 at the middle of the lower and upper limits. Data from the second elicitation exercise described in Chapter 3. μ= degree of membership.

3) Replace all answers given as linguistic terms by their respective IT2FS and combine/average their answers using the LWA to produce a single answer/value for each question (Fig. B.7).

Question Q_1: How likely is a marine farm (subtidal) to become infected when visited/used by a recreational vessel (moored)?

Answers: Expert 1_{Q1}= Very unlikely;

Expert 2–4 $_{Q1}$= Likely;

Expert 5 $_{Q1}$= Very likely.

Combining experts' answer $_{Q1}$: LWA $_{Q1}$ (1Very unlikely; 3Likely; 1Very likely)

4) Apply Sj (Jaccard similarity measure) to compare the resulting LWA$_{Q1}$ with the IT2FLs calculated in step 2 that represented the probability terms Very unlikely (Vu), Unlikely (U), Likely (L), and Very likely (Vl). The highest Sj indentifies the probability term (word) that best represent the calculated LWA $_{Q1}$ (average of the answers).

$S_j(\tilde{Y},\widetilde{Vu})$= 0.007; $S_j(\tilde{Y},\tilde{U})$= 0.047; $S_j(\tilde{Y},\tilde{L})$= 0.702; $S_j(\tilde{Y},\widetilde{Vu})$= 0.067

Linguistic answer= Likely

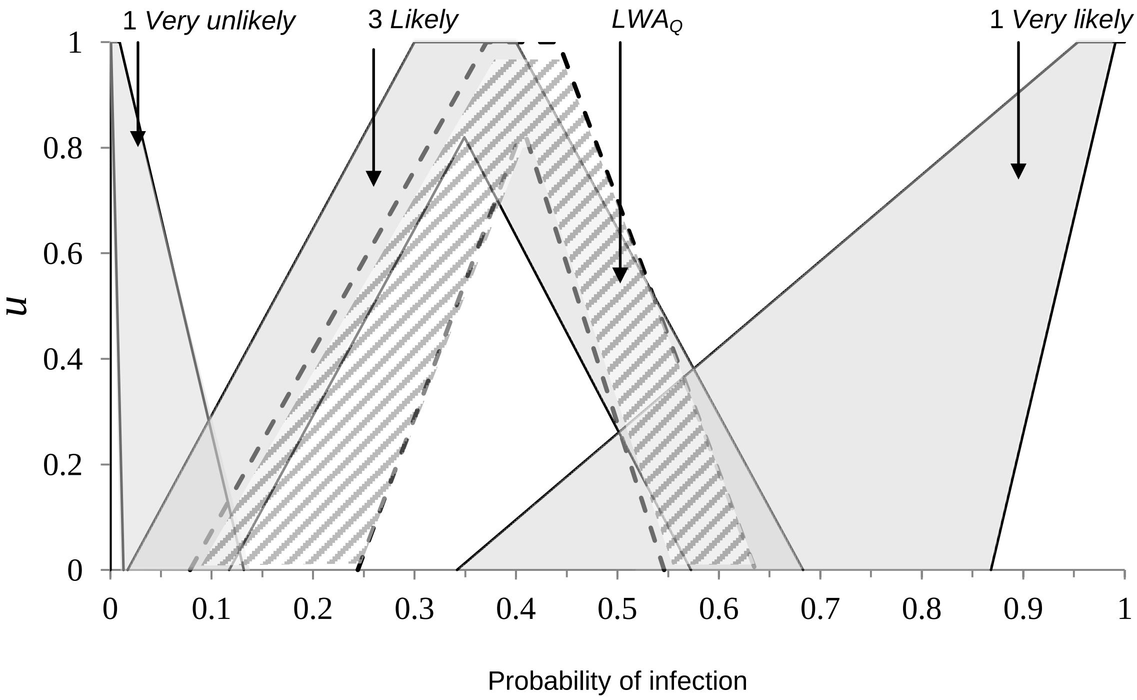


Figure B.7 Linguistic weighted average (LWA) of five expert answers to the question (Q1) 'How likely is it for boat ramps to become infected when visited/used by a trailered vessel?' 1 expert considered this event Very unlikely, 3 considered it Likely, and 1 considered it Very likely. Data from the second elicitation exercise described in Chapter 3. μ= degree of membership.

5) Compute the characterising left- and right-end points ($[C_l, C_r]$), of LWAQ1 using the Enhanced Karnik-Mendel algorithm (Eqs. B3 and B4) and calculate their mean.

[C_l= 0.33, C_r= 0.44] → ((0.33 + 0.44)/2)= 0.39

6) Calculate the variability (uncertainty) of the assessed probability as the distance between C_r and C_l.

$(C_l - C_r)$= 0.11

B.3 DIGITISED RECREATIONAL CRUISING ROUTES AND INITIAL SUB-REGIONS

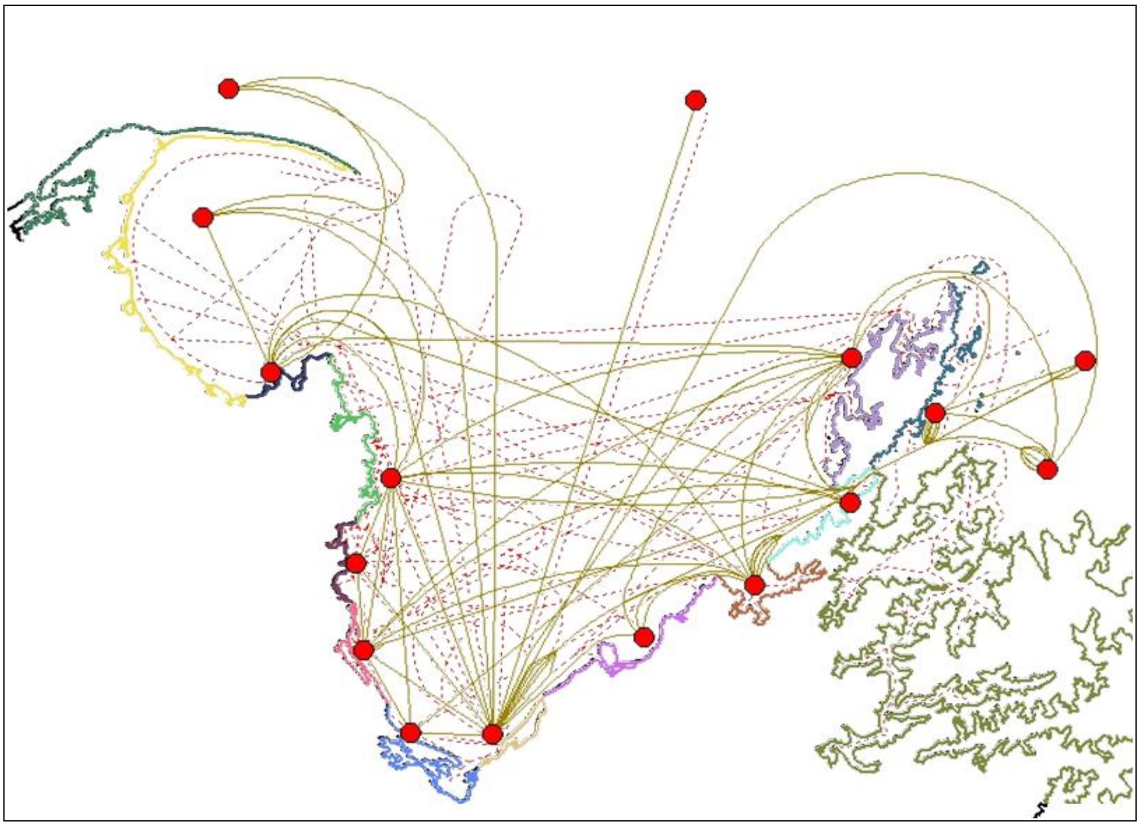


Figure B.8 Initial sub-regions. The study region was initially subdivided into 16 sub-regions (nodes) defined by an apparent grouping pattern of all digitised recreational routes. Nodes/Sub-regions are represented as gray circles. Results based on a mail survey conducted in Golden Bay and Tasman Bay in June–July, 2004, with an estimated response rate of 45.7%. Total number of vessels= 320 (205 moored and 115 trailered). Routes digitised with ArcGIS v. 8.3

B.4 RESULT OF THE χ^2 TEST FOR THE RELATION VESSEL TYPE–ACTIVITY

Table B.2 Results of the χ^2 tests for the relation vessel type and its activity. The results suggest recreation and fishing as the main use of most vessel types in both groups. Categories trailer yacht and barge (moored vessels), as well as keeler, multihull and motor-cruiser (trailered vessels) were not included in the χ^2 analyses because of their small representative numbers (< 3 vessels). Cha= charter, Div= diving, Fis= fishing, Rac= racing, Rec= recreation, Res= research, Tra= trailer.

Vessel Type	Activity						
Dinghy	Cha	Div	Fis	Rac	Rec	Res	Tra	All
Count	0	0	3	30	34	0	2	69
Expected	9.86	9.86	9.86	9.86	9.86	9.86	9.86	69
Cont to χ2	9.857	9.857	4.77	41.161	59.133	9.857	6.263	*
All	36	36	36	36	36	36	36	252
χ^2= 194.024, DF= 6, P-Value= 0.000" - Likelihood Ratio χ^2= 211.865, DF= 6, P-Value= 0.000"								
Trailer yacht	Cha	Div	Fis	Rac	Rec	Res	Tra	All
Count	6	6	13	13	31	0	7	76
Expected	10.86	10.86	10.86	10.86	10.86	10.86	10.86	76
Cont to χ2	2.173	2.173	0.423	0.423	37.37	10.857	1.37	*
All	33	33	33	33	33	33	33	231
χ^2= 81.654, DF= 6, P-Value= 0.004" – Likelihood Ratio χ^2= 92.379, DF= 6, P-Value= 0.001"								
Small powered craft	Cha	Div	Fis	Rac	Rec	Res	Tra	All
Count	14	11	37	0	30	0	16	108
Expected	15.43	15.43	15.43	15.43	15.43	15.43	15.43	108
Cont to χ2	0.132	1.271	30.16	15.429	13.762	15.429	0.021	*
All	43	43	43	43	43	43	43	301
χ^2= 118.846, DF= 6, P-Value= 0.000" – Likelihood Ratio χ^2= 145.551, DF= 6, P-Value= 0.000"								

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Appendix C: Chapter 4

C.1 INVITATION AND QUESTIONNAIRE–MARINE FARMERS

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet Produced: 01 Sept 2010

Project Title: Marine biosecurity in Golden Bay and Tasman Bay

An Invitation:

Dear *marine farmer*,

I am a postgraduate student from Auckland University of Technology and my research thesis is on marine biosecurity in New Zealand, with focus on Golden Bay and Tasman Bay. As part of the research I am identifying the movement of aquaculture products and gear in this region. Therefore, I am inviting you to participate in a survey that will provide essential information for this research.

Your participation in this survey is voluntary and you may withdraw at any time prior to the completion of data collection without any adverse consequences.

What is the purpose of this research?

The main objective of this research is to identify the components and processes of mussel aquaculture within Golden Bay and Tasman Bay.

How was I identified and why am I being invited to participate in this research?

You were identified because either:

1- your name/company appears in publicly available lists of people/companies involved with the aquaculture industry in the region (e.g. yellow pages, internet sites, published reports),

2- your name/company appears in a resource consent for a marine farm in the region, or

3- I have met you before and know you are (have been) involved with the aquaculture industry of this region.

You are invited to participate because I believe your knowledge of aquaculture processes in general, and Golden Bay and Tasman Bay's aquaculture, in particular, would be valuable to this project.

What will happen in this research?

As a participant in the survey you will be contacted with 1-2 questionnaires that take about 20 minutes to complete. The first questionnaire asks about general aquaculture practices and your habits as a marine farmer. Ideally, this questionnaire will be filled out during a personal interview. However, if you prefer so, you are welcome to fill it out on your own and post it back in a free-post envelope. The second questionnaire will simply ask you to review a diagram of the aquaculture in Golden Bay and Tasman Bay (based on the answers of the first questionnaire) and modify it if required. You will have up to 10 days to return this questionnaire in the free-post envelope.

What are the discomforts and risks and how will these discomforts and risks be alleviated?

The survey has been carefully designed and tested with several people, who considered all the questions straightforward, easy to answer and not intrusive. However, you may consider some of the questions asked of you to be legally or commercially sensitive. If for any reason you do not feel comfortable answering a particular question, you do not have to answer it. Also, you may withdraw from the survey at any time before the collection of data with no adverse consequences.

What are the benefits?

The present project would produce baseline information on the dynamics of aquaculture in Golden Bay and Tasman Bay. Such information is essential for the implementation of effective monitoring and control programs of non-indigenous species and aquaculture pests within the region.

How will my privacy be protected?

All the information you provide in the survey will be:
- not connected to your contact details in any way,
- kept confidential,
- only accessed by my supervisor and me,
- only used for the purpose of this research, and
- not shared with any other parties under any circumstances.

While there might be publications as a result of this study, your identity will remain anonymous as only averaged data and summaries will be presented.

What are the costs of participating in this research?

About 40 minutes of your busy life. You will NOT have to spend any money in postage as free-post envelopes will be provided.

What opportunity do I have to consider this invitation?

I would really appreciate if you let me know now whether or not you are interested in participating in the survey. However, if you need some time to think about it or consult with other people your potential participation, please let me know no later than October 26.

How do I agree to participate in this research?

Simply please fill out the *Consent Form* attached to this information.

Will I receive feedback on the results of this research?

Yes! If you are interested in receiving such a feedback, just tick this option in the *Consent Form*.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Andrea Alfaro, a.alfaro@aut.ac.nz , 921 9999 ext. 8197.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz , 921 9999 ext 8044.

Whom do I contact for further information about this research?

If you have any questions regarding this research please do not hesitate to contact me or my supervisor Dr. Andrea Alfaro

Researcher Contact Details:
Hernando Acosta
hacosta@aut.ac.nz
09-9219999 ext 8185
24 St. Paul Street, Auckland, New Zealand

Project Supervisor Contact Details:
Dr. Andrea Alfaro
a.alfaro@aut.ac.nz
09-9219999 ext 8197
24 St. Paul Street, Auckland, New Zealand.

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*,
AUTEC Reference number *type the reference number.*

Consent Form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***Marine biosecurity in Golden Bay and Tasman Bay, New Zealand***

Project Supervisor: ***Andrea Alfaro***

Researcher: ***Hernando Acosta***

☐ I have read and understood the information provided about this research project in the Information Sheet dated *01 Sept 2010*.

☐ I have had an opportunity to ask questions and to have them answered.

☐ I understand that questionnaires will be either self-administrated or filled out during the interview(s), and that additionally notes may be also taken.

☐ I understand that if an interview is conducted to fill out a questionnaire, additional notes may be also taken.

☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

☐ If I withdraw, I understand that all relevant information including questionnaires, emails, or parts thereof, will be destroyed.

☐ I agree to take part in this research.

I wish to receive a copy of the report from the research (please tick one): ☐ Yes ☐ No

Participant's signature:

Participant's name:

Date:

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010, AUTEC Reference number 10/224.

Note: The Participant should retain a copy of this form.

Aquaculture pathway in Golden Bay and Tasman Bay – Mussel farmers – Questionnaire

AUT UNIVERSITY

Company: ________________________ Contact: ___________________

Role: __________________________ Date: __________ Time: ____

1. CONCEPTUAL MODEL OF MUSSEL AQUACULTURE IN GOLDEN BAY AND TASMAN BAY

The objective of this first section is to gather baseline information for developing a conceptual model of the Greenshell mussel aquaculture process in Golden Bay and Tasman Bay.

Pag
1

1.1. The following diagram (Figure 1) is a conceptual representation of the aquaculture process in Golden Bay and Tasman Bay. Please analyse the model and make any changes you consider necessary to have a more comprehensive and/or accurate model.

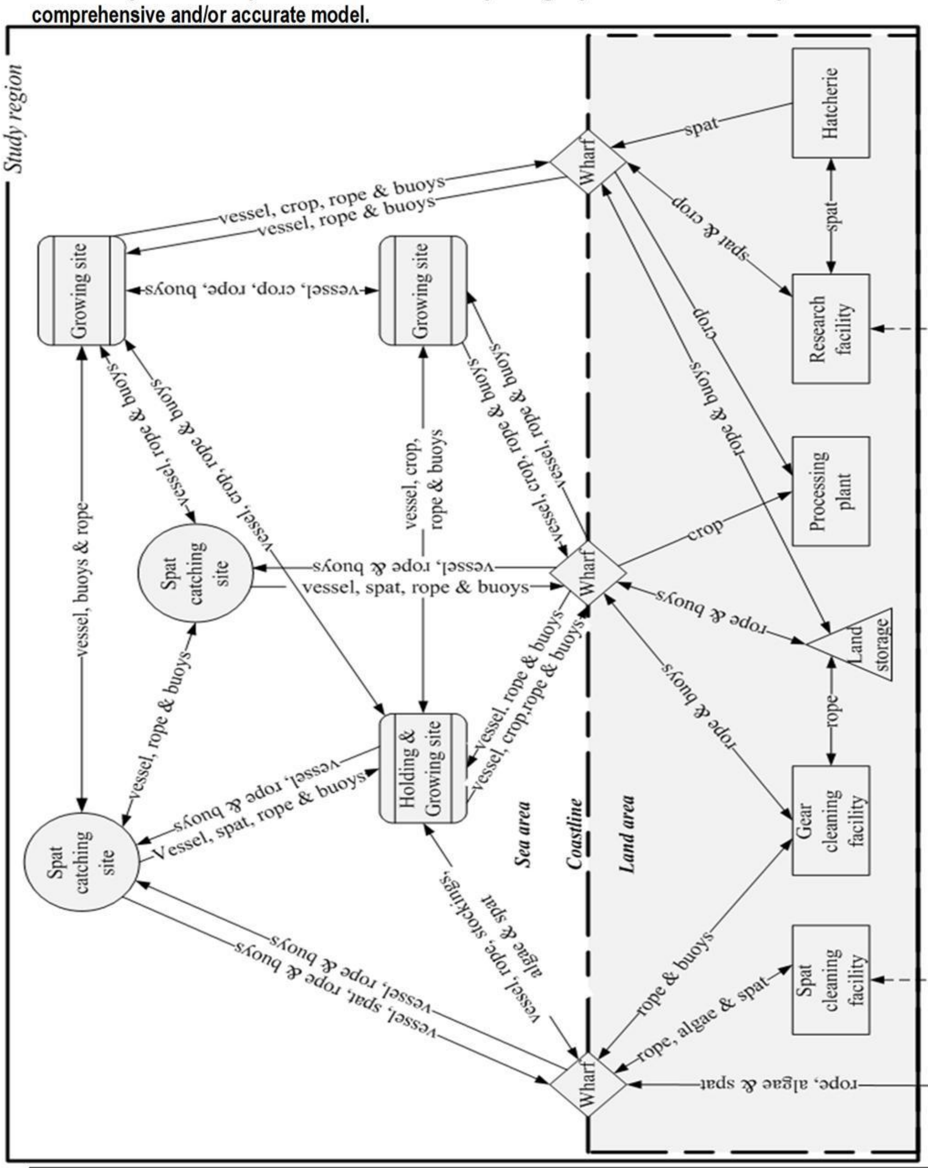

Figure 1. Movement of aquaculture gear, spat and product in Golden Bay and Tasman Bay.

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010. AUTEC Reference number 10-210

2. FARM LOCATION, SIZE, TYPE AND OPERATION

The objective of this section is to gather information on the location and size of your farm(s), whether your farm(s) is (are) used for spat catching or growing product, who operates the farm(s) and the species harvested.

2.1. Please circle in the map (Figure 2) where your farm(s) is (are) located within the Golden Bay and Tasman Bay region.

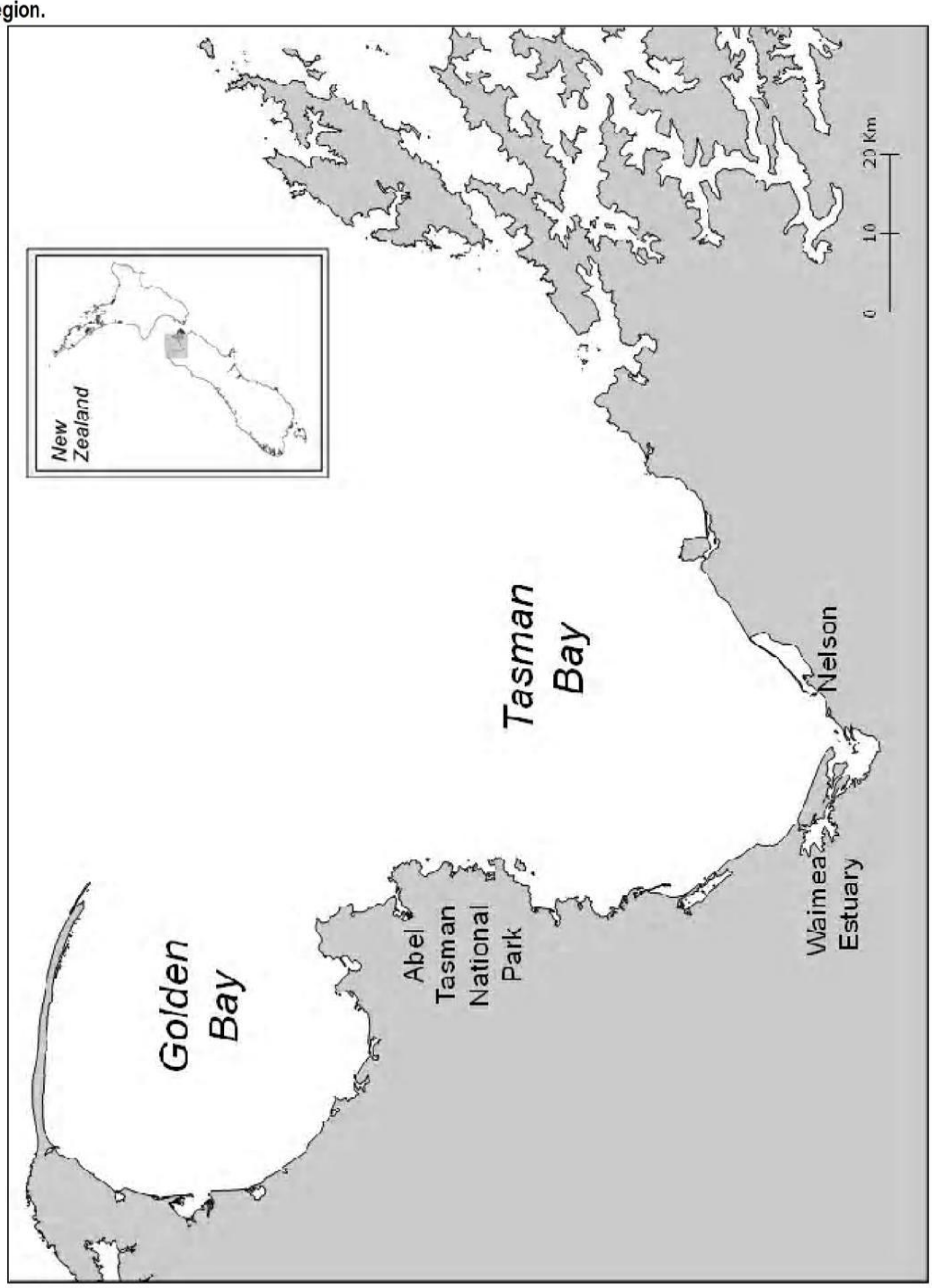

Figure 2. Golden Bay and Tasman Bay.

2.2. How many hectares of longline culture does your company own in Golden Bay and Tasman Bay? (e.g. ~~10ha~~)

□ none

□ _______**ha...→ Does your company operate your farm(s) (e.g. seeding, harvesting)?**

□ yes, it is in charge of all the activities in the farm(s) (i.e. seeding, harvesting, maintaining)

□ no, it is only in charge of (e.g. seeding) ____

→ Which companies are in charge of the other activities in your farm?_____________

____

□ no, it is not in charge of any activities in the farm

→ Which companies are in charge of the activities in your farm?____________________

____

2.3. Does your company operate mussel farms in Golden Bay and Tasman Bay that are owned by somebody else?

□ no

□ yes...**What kind of operation? (select all that apply)**

□ spat collection □ seeding □ harvesting □ environmental monitoring (e.g., biotoxin, rainfall)

□ farm maintenance (e.g. backbone maintenance) □ other (please specify) _____________________

2.4. Your farm is used for: (select all that apply)

□ only green mussel spat catching □ only green mussel growing → **go to section 4**

□ both, green mussel spat catching and growing □ other (please specify) _____________________

3. SPAT CATCHING FARMS

Please answer the following questions if you catch spat in your farm. Otherwise go to section 4.

3.1. The spat catching activity in this farm is:

□ seasonal but Permanent (i.e. you collect spat every year in this farm)

□ seasonal but Rotational → **This farm is used to collect spat every (e.g. 2 years)**_______________

3.2. Which months are you more likely to collect spat in this farm?

□ January	□ February	□ March	□ April	□ May	□ June
□ July	□ August	□ September	□ October	□ November	□ December

3.3. What spat catching gear you use in you farm? (select all that apply)

□ Spat ropes □ other (please specify): __________________________

3.4. Where is the spat collected in your farm used? (select all that apply):

□ in the same area where it is collected (same bay or harbour, e.g. Croisilles Harbour)

□ in other areas within Golden Bay and Tasman Bay

□ in the Marlborough Sounds

□ in other regions of New Zealand → **Please specify:** ______________________________________

3.5. If the spat is used in other farms, how is it transported there? (select all that apply)

□ spat is only used in the same farm(s) where it is collected

□ spat ropes are left in the water and towed directly to other farms

□ spat ropes are laid on the deck of a vessel and transported to other farms

□ spat ropes are stripped off on board and reseeded while transported to other farms

□ spat ropes are put inside bags on the deck of a vessel and transported to other farms

□ other (Please specify) ______________________________________

Approved by the Auckland University of Technology Ethics Committee on September 21, 2010. AUTEC Reference number 10-210

3.6. Please indicate in the following table (Table 1) which vessels are more likely to collect/transport the spat from your farm.

Table 1

Name of vessel	Type (e.g. harvesting, seeding)	Company that owns it

3.7. Are these vessels used in other farms or regions? (Select all that apply)

□ no, they only serve my farm
□ yes...→□ They serve other farms in Golden Bay
□ They serve other farms in Tasman Bay
□ They serve other farms in the Marlborough Sounds
□ They serve farms in other regions of New Zealand → **Please specify where:**_____________________
□ I do not know

3.8. Please indicate the ports, wharves and/or boat ramps where the spat collected in your farm is landed: (select all that apply)

□ *The spat is never landed (i.e. transported directly to farms by sea)*
□ Collingwood wharf □ Waitapu wharf □ Port Tarakohe □ Pohara wharf □ Port Motueka
□ Mapua wharf □ Port Nelson □ Okiwi wharf □ Havelock wharf □ Picton wharf
□ Port Underwood □ Kaiteriteri □ French Pass □ Jackson Bay
□ Other(s) ***please specify:*** ___________________, ________________________

3.9. Please fill out the following table (Table 2) indicating the region(s) the spat collected in your farm is taken to and whether it is transported by sea, road or air. Also indicate what percentage of the total spat collected in your farm during the season is transported to a particular region. Select "I do not know" if are unable to give an estimate of the percentage transported to that particular region.

	Table 2	% of total spat catch		Via		
	Spat taken to	%	I do not know	Sea	Road	Air
South Island	Offshore Collingwood		□	□	□	□
	Croisilles Harbour		□	□	□	□
	Wainui Bay		□	□	□	□
	Waikawa Bay		□	□	□	□
	Port Hardy		□	□	□	□
	Catherine Cove		□	□	□	□
	Admiralty Bay		□	□	□	□
	Marlborough Sounds		□	□	□	□
	Banks Peninsula		□	□	□	□
	Stewart Island		□	□	□	□
North Island	Northland		□	□	□	□
	Coromandel		□	□	□	□
Other:			□	□	□	□

3.10. When the spat catching season is over what do you do with the following gear? (select all that apply)

a) Back bone ropes
□ We do not use them in spat catching
□ leave them in the water
□ use them in the growing process
□ use them in other farms
□ store them on land
□ other: ____________________

b) Spat ropes (select all that apply)
□ We do not use them in spat catching
□ leave them in the water
□ use them in the growing process
□ use them in other farms
□ store them on land
□ other: : ____________________

c) Anchors
□ We do not use them in spat catching
□ leave them in the water
□ use them in the growing process
□ use them in other farms
□ store them on land
□ other: : ____________________

d) Buoys
□ We do not use them in spat catching
□ leave them in the water
□ use them in the growing process
□ use them in other farms
□ store them on land
□ other: : ____________________

d) Sack/Bags
□ We do not use them in spat catching
□ use them in the growing process
□ use them in other farms
□ store them on land
□ other: : ____________________

4. HARVESTING /GROWING FARMS

Please answer the following section if you harvest mussels in your farm(s).

4.1. Please fill out the following table (Table 3) indicating where the spat that you use in this farm usually comes from and which port, wharf or board ramp the spat is put onboard before it is moved into your farm(s). Write "*D*" if the spat is transported directly from the spat catching area to the farm(s) by vessel. Also indicate the usual months when each spat is available and the approximate percentage of the total spat from each location.

Table 3

		Months usually available												
Spat origin	**Boarding location**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**
Kaitaia		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Offshore Collingwood		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Offshore Onekaka		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Wainui Bay		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Offshore Kaiteriteri		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Offshore Motueka		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Offshore Moutere		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Croisilles Harbour		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Waikawa Bay		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Catherine Cove		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Port Hardy		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Marlborough Sounds		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Glenhaven Hatchery		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Other (please specify)		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

4.2. Which months are you more likely to collect and transport conditioned mussels from your farm? Conditioned mussels refers to those mussels that have reached a marketable size (90-120mm).

☐ January ☐ February ☐ March ☐ April ☐ May ☐ June
☐ July ☐ August ☐ September ☐ October ☐ November ☐ December

4.3. Please indicate in the following table (Table 4) the vessels that are more likely to collect/transport conditioned mussels from your farm? Conditioned mussels refers to those mussels that have reached a marketable size (90-120mm).

Table 4

Name of vessel	Type (e.g. harvesting, seeding)	Company that owns it

4.4. Are the vessels that collect/transport the mussels from your farm used in other farms? (select all that apply)

□ no, they only serve my farm
□ yes...→□ They serve other farms in Golden Bay
□ They serve other farms in Tasman Bay
□ They serve other farms in the Marlborough Sounds
□ They serve farms in other regions of New Zealand → **Please specify where:**____________________
□ I do not know

4.5. Do you move juveniles/growing mussels to/from farms in other bays/regions?

□ no
□ yes... → **How do you transport them between farms? (select all that apply):**
□ mussel ropes are left in the water and towed directly to other farms
□ ropes with mussels are laid on the deck of a vessel and transported to other farms
□ mussels are stripped off the ropes on board and reseeded while transported to other farms
□ ropes with mussels are put inside bags on the deck of a vessel and transported to other farms
□ other (Please specify) ____________________________________

4.6. Please indicate the ports, wharfs and/or boat ramps where the mussels harvested in your farm are landed. If these mussels are landed directly into a processing plant please indicate so by selecting the last option provided. (Select all that apply).

□ Collingwood wharf □ Waitapu wharf □ Port Tarakohe □ Pohara wharf □ Port Motueka
□ Mapua wharf □ Port Nelson □ Okiwi wharf □ Havelock wharf □ Picton wharf
□ Port Underwood □ Kaiteriteri □ French Pass □ Jackson Bay
□ Other(s) *please specify*: __________________, ______________________
□ Processing plant(s) located in ____

4.7. Please fill out the following table (Table 5) indicating in which plants the mussels harvested in your farm are processed and whether they are transported there by sea, road and/or air. Also indicate what percentage of the total annual production of your farm is moved to each plant. Select "I do not know" if you are unable to give an estimate of the percentage processed in a particular region.

Table 5	% of total annual production		Via		
Region	**%**	**I do not know**	**Sea**	**Road**	**Air**
Golden Bay		□	□	□	□
Motueka (Tally's)		□	□	□	□
Nelson (Sealord)		□	□	□	□
Nelson (Sanford)		□	□	□	□
Havelock (Sandford)		□	□	□	□
Christchurch (Pacifica plant)		□	□	□	□
Tauranga (NIMP – Sandford)		□	□	□	□
Bluff (Sandford)		□	□	□	□
Whitianga (OP Columbia)		□	□	□	□
Blenheim (Wakatu Incorp./Aoteroa Seafoods)		□	□	□	□
Other (please specify):		□	□	□	□
		□	□	□	□
		□	□	□	□
		□	□	□	□
		□	□	□	□

4.8. What do you do with the following gear when you are not using it in your farm for the growing process? (select all that apply)

a) Back bone ropes
□ leave them in the water
□ use them in spat catching
□ use them in other farms
□ store them on land
□ other: ________________

b) Culture ropes/Growing lines
□ leave them in the water
□ use them in spat catching
□ use them in other farms
□ store them on land
□ other: ________________

c) Anchors
□ leave them in the water
□ use them in spat process
□ use them in other farms
□ store them on land
□ other: ________________

d) Buoys
□ leave them in the water
□ use them in spat catching
□ use them in other farms
□ store them on land
□ other: ________________

d) Sacks/Bags
□ leave them in the water
□ use them in the spat catching
□ use them in other farms
□ store them on land
□ other: ________________

5. SPAT, PRODUCT AND GEAR EXCHANGE AND CLEANING

5.1. Please indicate how often you clean the following aquaculture product and gear, where you clean it and whether this is done by you or a specialized company.

a) SPAT/SEED

When?
□ never
□ only when it seems it needs it
□ always before seeding
□ I do not know
□ other:__________________

Where?
□ on land
□ on board
□ I do not know

Who does it?
□ The crew on board
□ We do it ourselves
□ a specialised company located in (e.g. Picton) ______________
□ other _________________

b) JUVENILE/GROWING MUSSELS

When?
□ never
□ only when it seems it needs it
□ always when moving them
□ I do not know
□ other:__________________

Where?
□ on land
□ on board
□ I do not know

Who does it?
□ The crew on board
□ We do it ourselves
□ a specialised company located in (e.g. Picton) ______________
□ other _________________

c) BACKBONE ROPES

When?
□ never
□ only when it seems it needs it
□ on regular basis:____________
□ I do not know
□ other:__________________

Where?
□ on land
□ on board
□ I do not know

Who does it?
□ The crew on board
□ We do it ourselves
□ a specialised company located in (e.g. Picton) ______________
□ other _________________

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d) CULTURE /GROWING LINES

When?	Where?	Who does it?
□ never	□ on land	□ The crew on board
□ only when it seems it needs it	□ on board	□ We do it ourselves
□ always before seeding	□ I do not know	□ a specialised company located in (e.g. Picton) _______________
□ on regular basis:_____________		□ other __________________
□ I do not know		
□ other:___________________		

e) SPAT ROPES

When?	Where?	Who does it?
□ never	□ on land	□ The crew on board
□ only when it seems it needs it	□ on board	□ We do it ourselves
□ always before seeding	□ I do not know	□ a specialised company located in (e.g. Picton) _______________
□ on regular basis:_____________		□ other __________________
□ I do not know		
□ other:___________________		

f) BUOYS

When?	Where?	Who does it?
□ never	□ on land	□ The crew on board
□ only when it seems it needs it	□ on board	□ We do it ourselves
□ on regular basis:_____________	□ I do not know	□ a specialised company located in (e.g. Picton) _______________
□ I do not know		□ other __________________
□ other:___________________		

g) ANCHORS

When?	Where?	Who does it?
□ never	□ on land	□ The crew on board
□ only when it seems it needs it	□ on board	□ We do it ourselves
□ on regular basis:_____________	□ I do not know	□ a specialised company located in (e.g. Picton) _______________
□ I do not know		□ other __________________
□ other:___________________		

d) SACKS/BAGS

When?	Where?	Who does it?
□ never	□ on land	□ The crew on board
□ only when it seems it needs it	□ on board	□ We do it ourselves
□ on regular basis:_____________	□ I do not know	□ a specialised company located in (e.g. Picton) _______________
□ I do not know		□ other __________________
□ other:___________________		

5.2. If you selected "Only when it seems it needs it" for any of the above questions, please indicate what you meant:

□ ____

□ I did not select that option

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5.3. Please select either *Very unlikely, Unlikely, Likely* or *Very likely* in the following table (Table 3) to indicate how likely you are to use in your farm aquaculture gear that has been used in farms from other bays/regions. Also indicate how likely you are to move into your farms juvenile/growing mussels from farms in other bays/regions.

Table 3

	HOW LIKELY			
Aquaculture item	**Very unlikely**	**Unlikely**	**Likely**	**Very likely**
Spat ropes	□	□	□	□
Culture ropes	□	□	□	□
Backbone ropes	□	□	□	□
Buoys	□	□	□	□
Anchors	□	□	□	□
SCUBA-diving gear	□	□	□	□
Juveniles/Growing mussels	□	□	□	□

5.4. Please select either *Very unlikely, Unlikely, Likely* or *Very likely* in the following table (Table 4) to indicate how likely it is for the gear that has been used in farms from other bays/regions to be cleaned before using it in your farm. If you moved juveniles/growing mussels from other farms/regions into your farm, also indicate how likely you are to clean them before transporting them into your farm.

Table 4

	HOW LIKELY			
Aquaculture item	**Very unlikely**	**Unlikely**	**Likely**	**Very likely**
Spat ropes	□	□	□	□
Culture ropes	□	□	□	□
Backbone ropes	□	□	□	□
Buoys	□	□	□	□
Anchors	□	□	□	□
SCUBA-diving gear	□	□	□	□
Juveniles/Growing mussels	□	□	□	□

5.5. Please connect with lines the places in column A with the places in column B to indicate all farming regions with which you exchange spat (S), juveniles/growing mussels (M) or gear (G). Circle S, M or G to specify what you exchange with that region. If there are other regions not listed please write them down in the blank spaces.

---------COLUMN A-----------	---------COLUMN B-----------
Collingwood__(S M G)□	□ Collingwood
Onekaka__(S M G)□	□ Onekaka
Wainui Bay__(S M G)□	□ Wainui Bay
Motueka__(S M G)□	□ Motueka
Kaiteriteri__(S M G)□	□ Kaiteriteri
Moutere__(S M G)□	□ Moutere
Croisilles Harbour__(S M G)□	□ Croisilles Harbour
Waikawa Bay__(S M G)□	□ Waikawa Bay
Catherine Cove __(S M G)□	□ Catherine Cover
Marlborough Sounds__(S M G)□	□ Marlborough Sounds
Port Hardy__(S M G)□	□ Port Hardy
Admiralty Bay__(S M G)□	□ Admiralty Bay
____________________(S M G)□	□ ________________
____________________(S M G)□	□ ________________
____________________(S M G)□	□ ________________

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5.6. Do you follow any guidelines when transporting spat/seed between farms?
□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________
□ always... →**Which guidelines do you follow?** ____
□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**__________________________

5.7. Do you follow any guidelines when transporting juveniles/growing mussels between farms?
□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________
□ always... →**Which guidelines do you follow?** ____
□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**__________________________

5.8. Do you follow any guidelines when transporting aquaculture gear between farms?
□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________
□ always... →**Which guidelines do you follow?** ____
□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**__________________________

5.9. Do you follow any guidelines for the cleaning of the spat/seed?
□ We never clean the spat/seed
□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________
□ always... →**Which guidelines do you follow?** ____
□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**__________________________

5.10. Do you follow any guidelines for the cleaning of the juveniles/growing mussels?
□ We never clean juveniles/growing mussels
□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________
□ always... →**Which guidelines do you follow?** ____
□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**__________________________

5.11. Do you follow any guidelines for the cleaning of aquaculture gear?

□ We never clean aquaculture gear

□ never... →**Why? (select all that apply)** □ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________________

□ always... →**Which guidelines do you follow?** ____

□ sometimes... →**Which guidelines do you follow?** ____
→ **What would determine that you follow these guidelines or not?**________________________

5.12. Based on your knowledge and experience in mussel farming in Golden Bay and Tasman Bay, please select either *Very unlikely, Unlikely, Likely* or *Very likely*, to indicate how likely it is for the following items to RETAIN water/sediment or fouling when used/taken out of the water and transported between farms. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). For example, someone could consider that Hooks are *Very unlikely* to retain water/sediment but *Likely* to retain fouling. Select NA if you consider that a particular item is NEVER taken out of the water or used in more than one farm. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item..

Table 5.

Aquaculture item	Material retained	NA	IDK	LIKELIHOOD: Very unlikely	Unlikely	Likely	Very likely
Spat/Seeds	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Juveniles/Growing mussels	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Spat ropes	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Culture ropes	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Buoys	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Anchors	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
On board declumping/harvesting machine/equipment	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
On board seeding machine/equipment	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Transporting sacks/bags	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
SCUBA-diving gear	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□

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AUT UNIVERSITY

5.13. Based on your knowledge and experience in mussel farming within Golden Bay and Tasman Bay, please select either *Very unlikely, Unlikely, Likely* or *Very likely*, to indicate how likely it is for the following items to be cleaned (i.e. removal of retained water/sediment and fouling) before being used in other farms. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). For example, someone could consider that Anchors are *Likely* to be cleaned between farms but Hooks are *Very unlikely* to be cleaned before transporting them into other farms. Select NA if you consider that a particular item is NEVER taken out of the water or used in more than one farm. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item.

Table 6.

Aquaculture item	NA	IDK	LIKELIHOOD			
			Very unlikely	Unlikely	Likely	Very likely
Spat/Seeds	☐	☐	☐	☐	☐	☐
Juveniles/Growing mussels	☐	☐	☐	☐	☐	☐
Spat ropes	☐	☐	☐	☐	☐	☐
Culture ropes	☐	☐	☐	☐	☐	☐
Buoys	☐	☐	☐	☐	☐	☐
Anchors	☐	☐	☐	☐	☐	☐
On board declumping/harvesting machine/equipment	☐	☐	☐	☐	☐	☐
On board seeding machine/equipment	☐	☐	☐	☐	☐	☐
Transporting sacks/bags	☐	☐	☐	☐	☐	☐
SCUBA-diving gear	☐	☐	☐	☐	☐	☐

5.14. Based on your knowledge and experience in mussel farming within Golden Bay and Tasman Bay, please indicate where the retained water/sediment and fouling originated from cleaning is discharged. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). Select NA if a particular item does not get cleaned between farms. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item.

Table 7

Aquaculture item	Material retained	NA	IDK	WHERE ARE CLEANING RESIDUES DISCHARGED?				
				Directly overboard	Onboard bins and then overboard	On board bins taken to land	Cleaning done on land	Other (please specify)
Spat/Seeds	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Juveniles/Growing mussels	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Spat ropes	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Culture ropes	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Buoys	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Anchors	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
On board declumping/ harvesting equipment	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
On board seeding equipment	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Transporting sacks/bags	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
SCUBA-diving gear	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	

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6. PROCESSING PLANTS, CLEANING FACILITIES AND AQUACULTURE VESSELS

The objective of this section is to gather information on the assets of the company and movement of vessels in the Bays.

6.1. Please indicate whether your company owns/operates processing plants, aquaculture vessels or gear cleaning facilities. Also specify their location.

□ processing plants → **Where?** ______________________________
□ gear cleaning facilities → **Where?** __________________________
□ spat cleaning facilities → **Where?** __________________________
□ aquaculture vessels...**Please specify (select all that apply)**
  □ harvesting vessels
  □ seeding vessels
  □ barges
  □ launch
  □ sourcing vessel
  □ other (please specify):_________________________________
□ the company does not own any of the above

6.2. If your company DOES NOT own/operate vessels used in the mussel industry please go straight to section 7, otherwise answer this question. Please fill out the following table (Table 8) with the name of your vessel(s) and usual regions and months where and when they operate.

Table 8

		Time of the year visited											
Vessel Name	**Region Visited**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□
		□	□	□	□	□	□	□	□	□	□	□	□

7. BIOSECURITY

This section has some questions on biosecurity. Remember that there are not right or wrong answers and all your answers will be confidential and only used for the purpose of this study. This study does not have any commercial implications.

7.1. Do you know what BIOSECURITY NEW ZEALAND is?

□ no
□ yes… → **What is it?** ____
____

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→ Which of the following *activities* and *environments* do you associate with BIOSECURITY NEW ZEALAND?

a)Activity (select all that apply)
- □ prevention
- □ control
- □ education
- □ research
- □ eradication
- □ I do not know any activity of Biosecurity New Zealand
- □ other (please specify): ___________________

b) Environment (select all that apply)
- □ laboratory environments
- □ marine environments
- □ airports
- □ freshwater environments
- □ terrestrial environments
- □ I do not know
- □ other (please specify): ______________________

7.2. Have you heard about the NEW ZEALAND MARINE UNWANTED ORGANISMS LIST?

□ no

□ yes… → **What is it?** ____ →

→ **Can you name any species from this list? -** ______________________________

□ no, I cannot

7.3. Please select *Yes* or *No* in the following table (Table 9) to indicate if you have heard about each of the listed organisms. Also indicate if you know any key characteristic(s) that would allow you to recognise the organism that you have heard about?

Table 9.

Common names	HAVE YOU HEARD ABOUT IT?		DO YOU KNOW ANY KEY CHARACTERISTICS TO IDENTIFY IT? (YES/NO)
Scientific names	**Yes**	**No**	**Which one(s)?**
Chinese mitten crab *Eriocheir sinensis*	□	□	
Mediterranean fanworm *Sabella spallanzanii*	□	□	
Dydimo *Didymosphenia geminata*	□	□	
European shore crab *Carcinus maenas*	□	□	
Gypsy moth *Lymantria dispar*	□	□	
Freshwater crayfish marron *Cherax tenuimanus*	□	□	
Asian clam *Potamocorbula amurensis*	□	□	
Asian kelp *Caulerpa taxifolia*	□	□	
Clubbed tunicate *Styela clava*	□	□	
Northern Pacific seastar, *Asterias amurensis*	□	□	
Whangamata seasquirt *Didemnum vexillum*	□	□	
Vase sea squirt *Ciona intestinalis*	□	□	

7.4. Have you seen any of these species in Golden Bay or Tasman Bay?

□ no
□ yes… → **Which ones?** ____
→ **When?** ____
→ **Please indicate in the map where you have seen each species**

8. ASSESSMENT OF TERMS OF LIKELIHOOD AND ADDITIONAL COMMENTS

The aim of the following question is to have an idea of what the terms *Very unlikely, Unlikely, Likely* and *Very likely* used in previous questions mean to you. Also to identify whether you would like to participate in future surveys and if you have any additional information you may want to share.

8.1. Please answer the questions below (i.e. write a number in the blank spaces ____) based on the following scenario:

"A man reaches into a bag of 100 golf balls and without looking grabs one"

If some balls are painted blue, you would describe his chances of grabbing a blue one as (see the example below):

a) Very Unlikely: if **no more** than ____ of the balls in the bag are blue,
b) Unlikely: if **no more** than ____ of the balls in the bag are blue,
c) Likely: if **no more** than ____ of the balls in the bag are blue, and
d) Very Likely: if **more** than c) of the balls in the bag are blue

For example, one might "describe his chances as '**remote**' if no more than *15* of the balls in the bag are blue"

8.2. How long have you been involved in the mussel industry for? (e.g. 3 years) ________________

8.3. Could I contact you again to review an updated version of the conceptual model of the Green mussel aquaculture industry (Figure 1)?

□ No, I prefer not to be contacted again
□ Yes, I am happy to review the model again

8.4. Do you have any additional information or comments you would like to add to this questionnaire?

____
____
____

THIS IS THE END OF THE SURVEY,
THANK YOU FOR TAKING THE TIME TO ANSWER THE QUESTIONS

Time:______________

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C.2 INVITATION AND QUESTIONNAIRE–SCIENTISTS

The question and diagram in page one and the map in question two of this questionnaire were the same already presented in Section C.1 so they are not included here.

Page 2–Question two:

‘**2. RESEARCH/INSPECTING LOCATIONS**

The objective of this section is to gather information on the locations where you are more likely to conduct your research or inspections.

Please circle in the map (Figure 2) the aquaculture locations that you normally visit within the Golden Bay and Tasman Bay region.’

2.2. Which months are you more likely to visit these locations?

□ January □ February □ March □ April □ May □ June
□ July □ August □ September □ October □ November □ December

2.3. Your research or inspections mainly related to:

□ only green mussel spat catching □ only green mussel growing □ both, green mussel spat catching and growing
□ other → **Please specify:** ____

2.4. What kind of gear you use when doing your research/inspections in the marine farms?

□ bottom-grab samplers □ quadrants □ traps/pots/cages □ suction samplers □ dredges
□ water samplers □ spades □ diving bags □ fishing rods □ hydrolabs/current meters
□ snorkeling/diving gear □ nets □ pile scrapings □ plankton nets □ bottom trawls
□ underwater camera □ ROV □ other (please specify): ________________________________

2.5. Please indicate the ports, wharves and/or boat ramps that you normally use when visiting marine farms.

□ Collingwood wharf □ Waitapu wharf □ Port Tarakohe □ Pohara wharf □ Port Motueka
□ Mapua wharf □ Port Nelson □ Okiwi wharf □ Havelock wharf □ Picton wharf
□ Port Underwood □ Kaiteriteri □ French Pass □ Jackson Bay
□ Other(s) **Please specify:** ____________________, __________________________

2.6. Do you move spat, juveniles/growing mussels or gear between bays/regions?

□ no
□ yes... → **What? (select all that apply):** □ spat □ juveniles/growing mussels □ gear

→ **How do move spat or juveniles/growing mussels? (select all that apply):**

□ ropes are left in the water and towed directly to other farms
□ ropes are laid on the deck of a vessel and transported to other farms
□ ropes are stripped off spat/mussels on board and reseeded while transported to other farms
□ ropes are put inside bags on the deck of a vessel and transported to other farms
□ other (Please specify) ____

→ **Please connect with lines the places in column A with the places in column B to indicate all farming regions with which you exchange spat (S), juveniles/growing mussels (M) or gear (G). Circle S, M or G to specify what you exchange with that region. If there are other regions not listed please write them down in the blank spaces.**

--------COLUMN A----------	---------COLUMN B----------
Collingwood__(S M G)□	□ Collingwood
Onekaka__(S M G)□	□ Onekaka
Wainui Bay__(S M G)□	□ Wainui Bay
Motueka__(S M G)□	□ Motueka
Kaiteriteri__(S M G)□	□ Kaiteriteri
Moutere__(S M G)□	□ Moutere
Croisilles Harbour__(S M G)□	□ Croisilles Harbour
Waikawa Bay__(S M G)□	□ Waikawa Bay
Catherine Cove __(S M G)□	□ Catherine Cover
Marlborough Sounds__(S M G)□	□ Marlborough Sounds
Port Hardy__(S M G)□	□ Port Hardy
Admiralty Bay__(S M G)□	□ Admiralty Bay
____________________(S M G)□	□ ________________
____________________(S M G)□	□ ________________
____________________(S M G)□	□ ________________

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Aquaculture Pathway in Golden Bay and Tasman Bay – Researchers/Farm Inspectors

2.7. Do you follow any guidelines when transporting spat/seed between farms?

□ Not applicable
□ never... →**Why? (select all that apply)**
□ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________
□ always... →**Which guidelines do you follow?** ______________________________
□ sometimes... →**Which guidelines do you follow?** ______________________________
→ **What would determine that you follow these guidelines or not?** ______________________

2.8. Do you follow any guidelines when transporting juveniles/growing mussels between farms?

□ Not applicable
□ never... →**Why? (select all that apply)**
□ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________
□ always... →**Which guidelines do you follow?** ______________________________
□ sometimes... →**Which guidelines do you follow?** ______________________________
→ **What would determine that you follow these guidelines or not?** ______________________

2.9. Do you follow any guidelines when transporting aquaculture gear between farms?

□ Not applicable
□ never... →**Why? (select all that apply)**
□ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________
□ always... →**Which guidelines do you follow?** ______________________________
□ sometimes... →**Which guidelines do you follow?** ______________________________
→ **What would determine that you follow these guidelines or not?** ______________________

---

3. CLEANING OF AQUACULTURE GEAR AND PRODUCTS

This section is about the cleaning of aquaculture gear and products in Golden Bay and Tasman Bay.

3.1. Do you follow any guidelines for the cleaning of the spat/seed?

□ Not applicable
□ never... →**Why? (select all that apply)**
□ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________□
□ always.... →**Which guidelines do you follow?** ______________________________
□ sometimes... →**Which guidelines do you follow?** ______________________________
→ **What would determine that you follow these guidelines or not?** ______________________

3.2. Do you follow any guidelines for the cleaning of the juveniles/growing mussels?

□ Not applicable
□ never... →**Why? (select all that apply)**
□ I do not know of any guidelines
□ I do not consider it necessary
□ following available guidelines are costly in terms of money/operating time
□ other (please specify): ______________________________
□ always... →**Which guidelines do you follow?** ______________________________
□ sometimes... →**Which guidelines do you follow?** ______________________________
→ **What would determine that you follow these guidelines or not?** ______________________

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Aquaculture Pathway in Golden Bay and Tasman Bay – Researchers/Farm Inspectors

3.3. Do you follow any guidelines for the cleaning of gear used in the farms?

□ Not applicable
□ never... →**Why? (select all that apply)**
- □ I do not know of any guidelines
- □ I do not consider it necessary
- □ following available guidelines are costly in terms of money/operating time
- □ other (please specify): ____________________

□ always... →**Which guidelines do you follow?** ____________________
□ sometimes... →**Which guidelines do you follow?** ____________________
→ **What would determine that you follow these guidelines or not?** ____________________

3.4. Based on your knowledge and experience in mussel farming in Golden Bay and Tasman Bay, please select either *Very unlikely, Unlikely, Likely* or *Very likely*, to indicate how likely it is for the following items to RETAIN water/sediment or fouling when used/taken out of the water and transported between farms. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). For example, someone could consider that Hooks are "*Very unlikely*" to retain water/sediment but "*Likely*" to retain fouling. Select NA if you consider that a particular item is NEVER taken out of the water or used in more than one farm. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item.

Table 1.

Aquaculture item	Material retained	NA	IDK	LIKELIHOOD: Very unlikely	Unlikely	Likely	Very likely
Spat/Seeds	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Juveniles/Growing mussels	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Spat ropes	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Culture ropes	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Buoys	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Anchors	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
On board declumping/harvesting machine/equipment	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
On board seeding machine/equipment	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
Transporting sacks/bags	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□
SCUBA-diving gear	Water/Sediment	□	□	□	□	□	□
	Fouling	□	□	□	□	□	□

3.5. Based on your knowledge and experience in mussel farming within Golden Bay and Tasman Bay, please select on Table 2 either *Very unlikely, Unlikely, Likely* or *Very likely*, to indicate how likely it is for the listed items to be cleaned (i.e. removal of retained water/sediment and fouling) before being used in other farms. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). For example, someone could consider that Anchors are "Likely" to be cleaned between farms but Hooks are "*Very unlikely*" to be cleaned before transporting them into other farms. Select NA if you consider that a particular item is NEVER taken out of the water or used in more than one farm. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item.

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Aquaculture Pathway in Golden Bay and Tasman Bay – Researchers/Farm Inspectors

Table 2

Aquaculture item	NA	IDK	LIKELIHOOD Very unlikely	Unlikely	Likely	Very likely
Spat/Seeds	☐	☐	☐	☐	☐	☐
Juveniles/Growing mussels	☐	☐	☐	☐	☐	☐
Spat ropes	☐	☐	☐	☐	☐	☐
Culture ropes	☐	☐	☐	☐	☐	☐
Buoys	☐	☐	☐	☐	☐	☐
Anchors	☐	☐	☐	☐	☐	☐
On board declumping/harvesting machine/equipment	☐	☐	☐	☐	☐	☐
On board seeding machine/equipment	☐	☐	☐	☐	☐	☐
Transporting sacks/bags	☐	☐	☐	☐	☐	☐
SCUBA-diving gear	☐	☐	☐	☐	☐	☐

3.6. Based on your knowledge and experience in mussel farming within Golden Bay and Tasman Bay, please indicate where the retained water/sediment and fouling originated from cleaning is discharged. Fouling here refers not only to firmly attached organisms (e.g. barnacles) but also to organisms that are entangled (e.g. seaweed entangled in hook). Select NA if a particular item does not get cleaned between farms. Select IDK (I DO NOT KNOW) if you consider your experience and knowledge of the process does not let you give an answer for a particular item.

Table 3

Aquaculture item	Material retained	NA	IDK	WHERE ARE CLEANUNG RESIDUES DISCHARGED? Directly overboard	Onboard bins and then overboard	On board bins taken to land	Cleaning done on land	Other (please specify)
Spat/Seeds	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Juveniles/Growing mussels	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Spat ropes	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Culture ropes	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Buoys	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Anchors	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
On board declumping/ harvesting equipment	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
On board seeding equipment	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
Transporting sacks/bags	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	
SCUBA-diving gear	Water/Sediment	☐	☐	☐	☐	☐	☐	
	Fouling	☐	☐	☐	☐	☐	☐	

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Aquaculture Pathway in Golden Bay and Tasman Bay – Researchers/Farm Inspectors

4. BIOSECURITY

This section has some questions on biosecurity. Remember that there are not right or wrong answers and all your answers will be confidential and only used for the purpose of this study. This study does not have any commercial implications.

4.1. Have you heard about the NEW ZEALAND MARINE UNWANTED ORGANISMS LIST?

□ no
□ yes… → **What is it?** ____________________
→ **Can you name any species from this list? -** ____________________
□ no, I cannot

4.2. Do you know what BIOSECURITY NEW ZEALAND is?

□ no
□ yes… → **What is it?** ____________________
____

→ **Which of the following *activities* and *environments* do you associate with BIOSECURITY NEW ZEALAND?**

a)Activity (select all that apply)
□ prevention
□ control
□ education
□ research
□ eradication
□ I do not know any activity of Biosecurity New Zealand
□ other (please specify): ____________________

b) Environment (select all that apply)
□ laboratory environments
□ marine environments
□ airports
□ freshwater environments
□ terrestrial environments
□ I do not know
□ other (please specify): ____________________

4.3. Please select Yes or No in the following table (Table 4) to indicate if you have heard about each of the listed organisms. Also indicate if you know any key characteristic(s) that would allow you to recognise the organism that you have heard about?

Table 4.

Common names	HAVE YOU HEARD ABOUT IT?		DO YOU KNOW ANY KEY CHARACTERISTICS TO IDENTIFY IT? (YES/NO)
Scientific names	**Yes**	**No**	**Which one(s)?**
Chinese mitten crab *Eriocheir sinensis*	□	□	
Mediterranean fanworm *Sabella spallanzanii*	□	□	
Dydimo *Didymosphenia geminata*	□	□	
European shore crab *Carcinus maenas*	□	□	
Gypsy moth *Lymantria dispar*	□	□	
Freshwater crayfish marron *Cherax tenuimanus*	□	□	
Asian clam *Potamocorbula amurensis*	□	□	
Asian kelp *Caulerpa taxifolia*	□	□	
Clubbed tunicate *Styela clava*	□	□	
Northern Pacific seastar, *Asterias amurensis*	□	□	
Whangamata seasquirt *Dydemnum vesillum*	□	□	
Vase sea squirt *Ciona intestinalis*	□	□	

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Aquaculture Pathway in Golden Bay and Tasman Bay – Researchers/Farm Inspectors

4.4. Have you seen any of these species in Golden Bay or Tasman Bay?

□ no

□ yes… → **Which ones?** ____________________

→ **When?** ____________________

→ **Please indicate in the map where you have seen each species**

5. ASSESSMENT OF TERMS OF LIKELIHOOD AND ADDITIONAL COMMENTS

The aim of the following question is to have an idea of what the terms *Very unlikely, Unlikely, Likely* and *Very likely* used in previous questions mean to you. Also to identify whether you would like to participate in future surveys and if you have any additional information you may want to share.

5.1. Please answer the questions below (i.e. write a number in the blank spaces ____) based on the following scenario:

"A man reaches into a bag of 100 golf balls and without looking grabs one"

If some balls are painted blue, you would describe his chances of grabbing a blue one as (see the example below):

- **a) Very Unlikely**: if **no more** than ____ of the balls in the bag are blue,
- **b) Unlikely**: if **no more** than ____ of the balls in the bag are blue,
- **c) Likely**: if **no more** than ____ of the balls in the bag are blue, and
- **d) Very Likely**: if **more** than _c)_ of the balls in the bag are blue

For example, one might "describe his chances as '**remote**' if no more than _20_ of the balls in the bag are blue"

5.2. How long have you been involved in aquaculture research for? (e.g. 5 years)____________________

5.3. Could I contact you again to review an updated version of the conceptual model of the Green mussel aquaculture industry (Figure 1)?

□ No, I prefer not to be contacted again

□ Yes, I am happy to review the model again

5.4. Do you have any additional information or comments you would like to add to this questionnaire?

____

____

____

Current time:________________

THIS IS THE END OF THE SURVEY,
THANK YOU FOR TAKING THE TIME TO ANSWER THE QUESTIONS

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C.3 SECOND EXERCISE–MARINE FARMERS AND SCIENTISTS

Dear *Participant's name,*

Thanks for agreeing to review the attached models. You could actually review the models (which are saved as a word file) whenever it suits you and email me your feedback.

These models were created/updated with information collected from a group of stakeholders (you included) of the mussel aquaculture industry in Golden Bay and Tasman Bay. The models describe the movement of aquaculture gear, spat and product within these regions.

Could you please analyse both figures and based on your knowledge of the aquaculture industry of these regions list any suggestions/changes that you consider necessary to have a more comprehensive/accurate conceptual model. If you consider that the models do not need any changes please state so. Please remember that the models focus only on Golden Bay and Tasman Bay. The models are pretty straightforward but do not hesitate to contact me if you want me to clarify anything.

I would really appreciate if you could email me your suggestions before *Date*

Once again, thank you for your help with this, I do appreciate it.

Regards,

Hernando Acosta
Earth and Oceanic Research Institute
Auckland University of Technology
ph: 09 917 9999 ext 8185

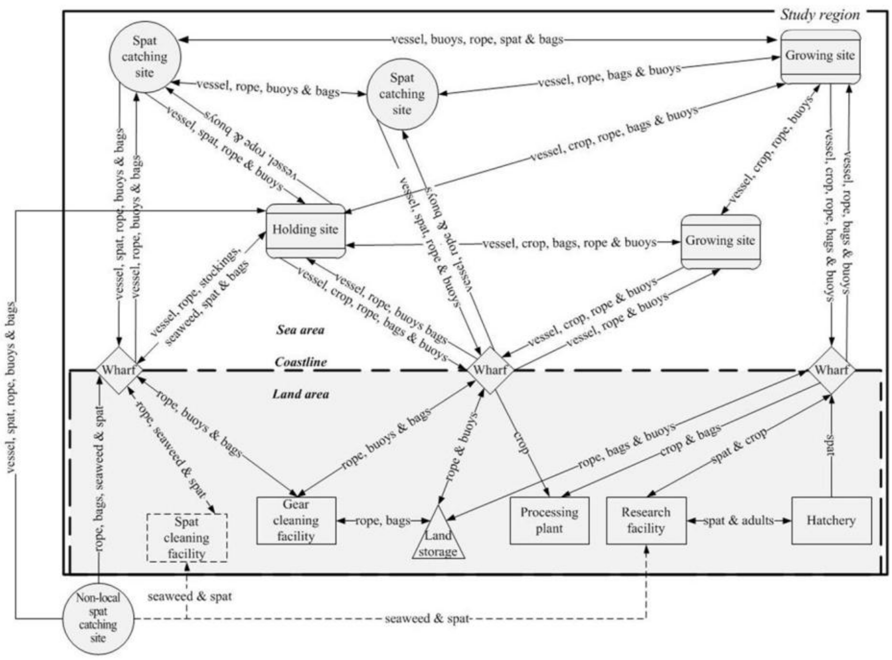

Figure 1. Aquaculture process in **Golden Bay and Tasman Bay.** Spat cleaning facilities are only used if required.

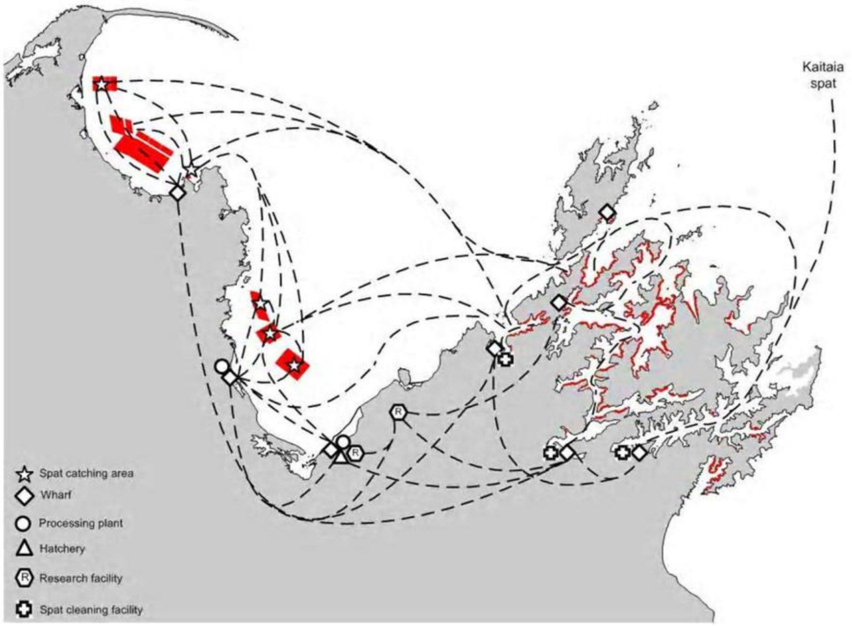

Figure 2. Movement of aquaculture gear, spat and growing and conditioned mussels in **Golden Bay and Tasman Bay**. Spat cleaning facilities are only used if required.

Appendix D: Chapter 5

D.1 MEAN CURRENT VALUES FOR NINE SITES AND FIVE DEPTH CATEGORIES IN GOLDEN BAY AND TASMAN BAY

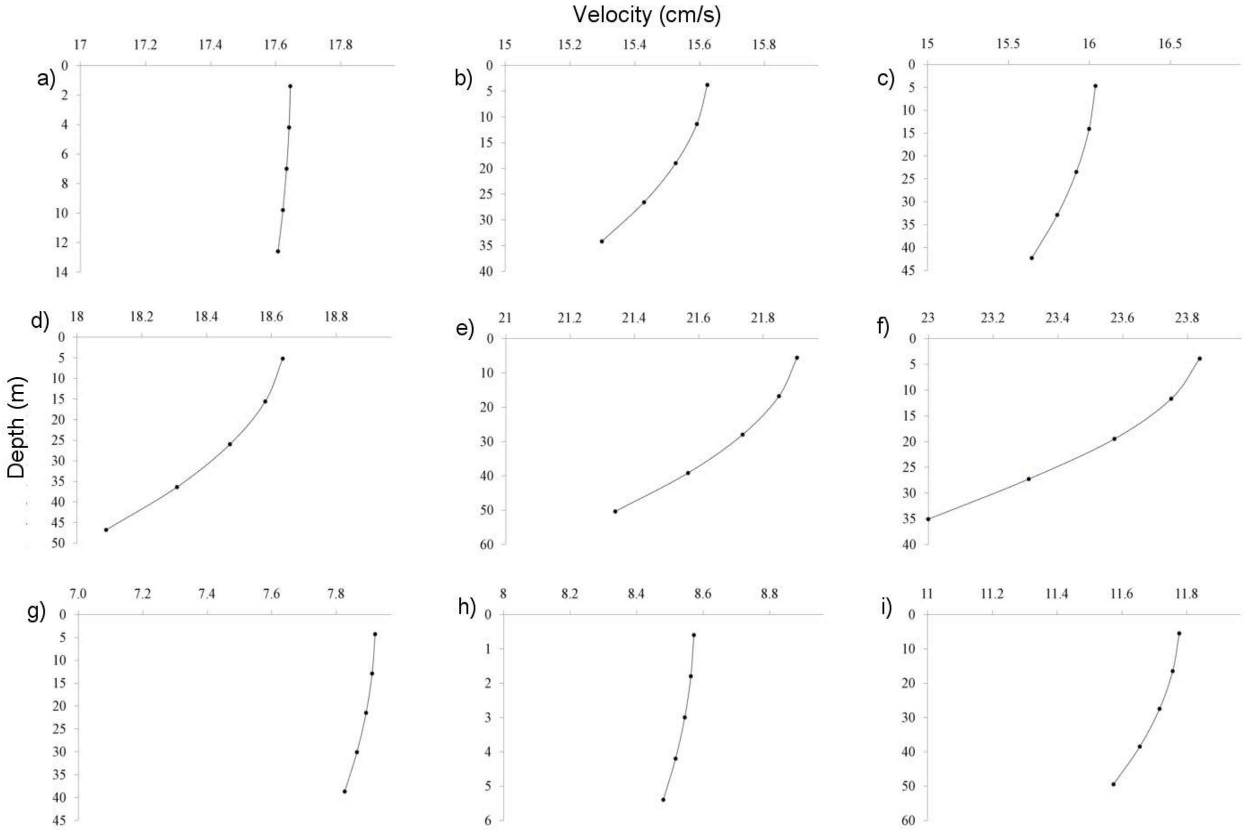

Figure D.1 Mean current values of 30 days of hourly data for nine sites (a–i) at five depth categories. Current values calculated using the validated three-dimensional numerical model described by Tuckey et al. (2006) that simulates hydrodynamic flows within the study region at five depth categories and at a resolution of 2.5 km^2. See Figure D.2 for the specific location of each site.

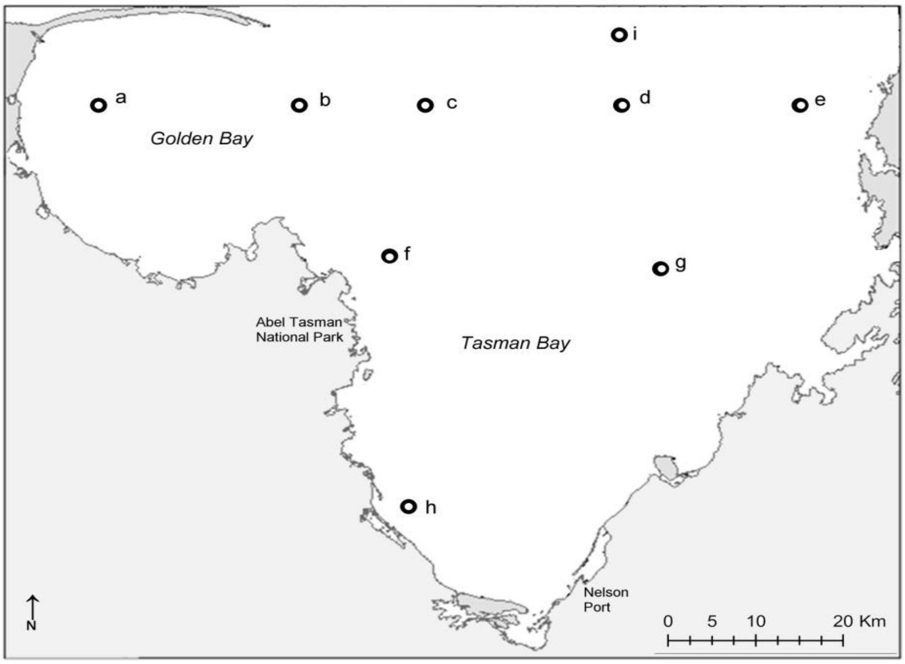

Figure D.2 Nine locations (a–i) used to measure mean current values of 30 days of hourly data. See Figure D.1 for results.

D.2 COMPUTATIONAL TIME VS. NUMBER OF PARTICLES

Table D.1 Model computational time for a simulation using different number of particles. The same hydrodynamic conditions and pelagic propagule duration (i.e., 15 days) were used to repeat the simulation.

Number of particles	Computational time (seconds)
50	14
100	**17**
500	35
1000	57
5000	251
10000	490

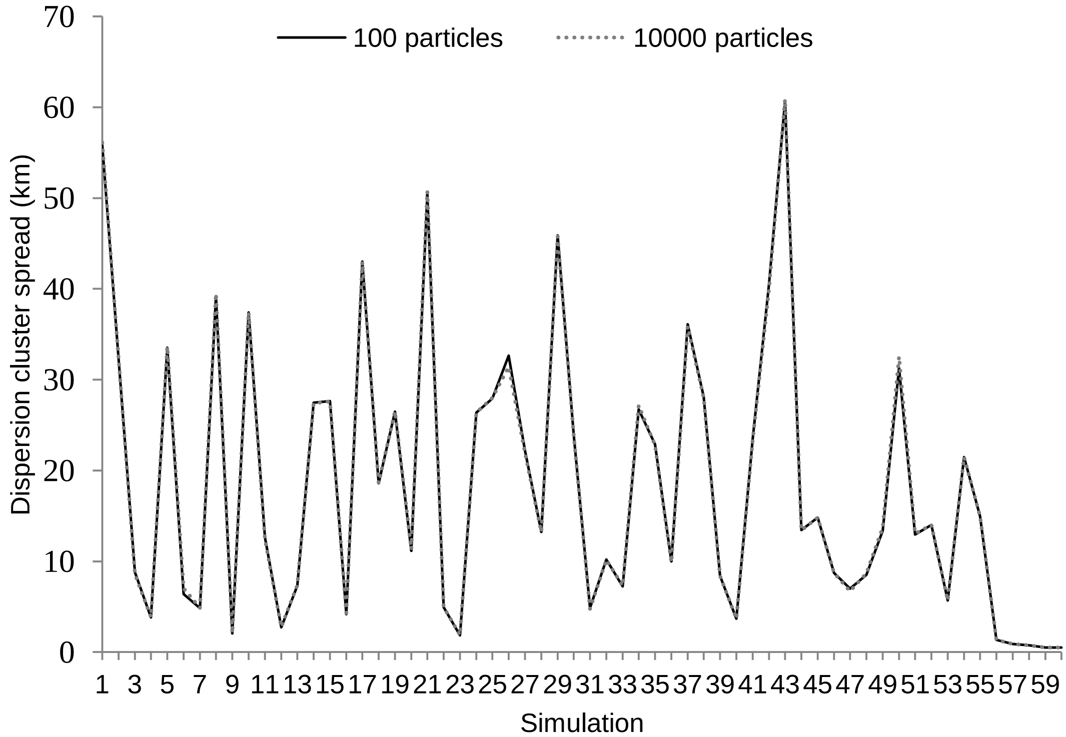

Figure D.3 Dispersion cluster spread using 100 and 10000 particles. Pelagic propagule duration (PPD)= 15 days. Total number of simulations= 60.

REFERENCE

Tuckey B.J., Gibbs, M.T., Knight, B.R. and P.A. Gillespie. 2006. Tidal circulation in Tasman and Golden Bays: implications for river plume behaviour. New Zealand Journal of Marine and Freshwater Research 40: 305–324.