

Invasive Alien Species biosecurity in England and Wales

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Declaration

The candidate confirms that the work submitted is their own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

This PhD was funded by NERC DTP and was jointly supervised by Drs Alison Dunn and Claire Quinn at the University of Leeds and Dr Paul Stebbing at Cefas. Parts of this thesis have been published in the following journals:

Chapter 2: Shannon, C., Quinn, C.H., Sutcliffe, C., Stebbing, P.D., Dally, T., Glover, A., Dunn, A.M. 2018. Exploring knowledge, perception of risk and biosecurity practices among researchers in the UK: a quantitative survey. *Biological Invasions*. **21**(2), pp.303-314. doi: 10.1007/s10530-018-1837-6

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I am lead author on the above articles. They all originate from my PhD research meaning I designed the research questions, methodology; as well as collected and analysed the data. These articles were co-authored with my supervisors whose role was in the recommendation of revisions and edits to manuscripts.

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Rationale for thesis by alternative format

The primary research aim for this thesis was to understand the effectiveness of existing invasive alien species (IAS) interventions designed to change specified biosecurity behaviour patterns. This thesis applied an interdisciplinary approach (drawing from methods and approaches from a combination of biological, social and political science) and used the Theory of Planned Behaviour as a framework to explore the human dimensions which are important factors to understand and manage IAS. The thesis also applies a mixed methods approach including biological and social science methodologies. The thesis produced five results chapter, and achieved two published academic papers, therefore I present the thesis by publication.

The thesis consists of an introductory chapter which sets out the context and rationale for the thesis. It introduces the process of biological invasions and the current political approach and literature around preventing future introductions and spread. It introduces the human dimensions of IAS prevention and outlines the overarching conceptual framework and details the research objectives and approach to data collection for each chapter. Paper 1 (Chapter 2) explores knowledge, perception of risk and biosecurity practices among field researchers in the UK. Paper 2 (Chapter 5) investigates the effectiveness of hot water treatment on the mortality of four invasive aquatic species.

The published chapters and additional research chapters are followed by a discussion and conclusion that reflects on the research approach and conceptual framework, limitations of the thesis and recommends possible future research directions.

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Abstract

Biological invasions have been recognised as the one of the greatest threats, after habitat loss, to biodiversity globally. Non-native species, also called alien species (as used by the Convention on Biological Diversity (CBD)), are species moved (intentionally or unintentionally) through human activity outside their natural distribution into novel terrestrial, freshwater and marine environments. Throughout history, humans have been moving and transporting species around the world, but as a result of global transport, trade and recreation, the rate of introductions is increasing. Non-native species that have negative ecological, economic or social impacts in their novel range are termed invasive alien species (IAS). Methods to prevent the introduction and spread of IAS are increasingly being recognised as the most cost effective means of reducing the impacts of IAS and are central to the CBD, EU Regulation 1143/2014 and the Invasive Non-Native Species Strategy for Great Britain. Biosecurity measures cover all activities aimed at preventing the introduction and/or spread of IAS.

Since IAS result from human activities, it is necessary to look at the human dimensions of IAS management. Research on the social psychological processes that shape stakeholder opinions and behaviours can help agencies structure interventions in a way that motivates people to act more consistently. This thesis applied an interdisciplinary approach and used Ajzen's Theory of Planned Behaviour as a framework to explore the human dimensions which are important factors to understand and manage IAS. The thesis applied a mixed methods approach including biological and social science methodologies.

Individual dimensions (e.g. knowledge, risk, attitudes, experience) helped to determine individuals' intentions to adopt preventative behaviours; and group dimensions (e.g. subjective norms, social networks) played an essential role especially in this thesis for water users. This thesis was able to confirm that awareness around IAS and communication campaigns such as *Check Clean Dry* is increasing. However, whilst these dimensions were useful to determine an individual's intention to behave, stakeholders perceived a lack of behavioural control as the behaviour was difficult to actually perform without the right infrastructure in place (e.g. cleaning stations). Whilst interventions such as local information, awareness campaigns, signs, training and legislative measures have been implemented in an attempt to increase perceived behavioural control, they should be not assume behaviour change.

To increase intention to behave the UK government should invest in infrastructure at high risk and highly used sites. Providing infrastructure for stakeholders will bridge the gap between intention to behave and actually changing behaviours. For example, as more individuals use

wash down stations, this will increase visibility of biosecurity behaviour; seeing people use wash down stations can potentially have a positive effect in encouraging others to wash down their equipment and therefore create a social norm spread through social networks.

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List of acronyms and abbreviations

BWM – Ballast Water Management

CBD – Convention on Biological Diversity

Defra – Department for Environment, Food and Rural Affairs

EU – European Union

FHI – Fish Health Inspectorate

GB – Great Britain

GBNNS – Great Britain Non-Native Species

IAS – Invasive Alien Species

IMO – International Maritime Organisation

INNS – Invasive Non-Native Species

MSFD – Marine Strategy Framework Directive

NNS – Non-Native Species

UK – United Kingdom

VLE – Virtual Learning Environment

WFD – Water Framework Directive

One individual cannot possibly make a difference, alone. It is individual efforts, collectively, that make a noticeable difference—all the difference in the world!

Dr Jane Goodall

Chapter 1: General Introduction, research approach and research objectives

Over the last century there has been a dramatic increase in the movement of non-native species around the world, as a consequence of international trade and travel (Hulme 2009; Seebens et al. 2018). Non-native species are species that have been introduced (intentionally or unintentionally) and established in an area outside of their native region (Kettunen et al. 2009). In the United Kingdom (UK) there are over 2000 established non-native species, but only 10-15% of these cause significant adverse effects on the environment, economy and society (Defra 2015). Those non-native species that have negative ecological, economic or social impacts are termed invasive alien species (IAS) (IUCN 2019) (the term IAS is synonymous with invasive non-native species (INNS)) (Defra 2015). The Millennium Ecosystem Assessment designated IAS, alongside climate change, habitat destruction, pollution and overexploitation, as one of the main drivers of biodiversity loss globally (MEA 2005). IAS affect marine, aquatic and terrestrial environments. Aquatic environments are particularly vulnerable and appear to be more susceptible to invasion to IAS (Dudgeon et al. 2006; Moorhouse and Macdonald 2015; Tricarico et al. 2016).

IAS can have huge economic impacts through loss of production, damage to infrastructure, the cost of combating IAS that are a threat to human health, either as direct agents of disease or as vectors or carriers of disease-causing parasites. In the European Union (EU), the impacts of IAS are estimated to cost approximately €12.5 billion a year (Kettunen et al. 2009). The current estimated cost of IAS to the UK economy is £1.7 billion with costs set to rise as climate change increases the potential for species to spread into new environments (Williams et al. 2010).

Biological invasion is the process in which IAS are introduced, establish and spread outside their native range. Many human activities lead to the intentional or unintentional movement of individual species to regions outside their native range (Chapple et al. 2012), although only a small subset of individuals that are transported to new regions manage to pass successfully through each stage of the introduction process to become invasive (Blackburn et al. 2011).

Pathways are the processes that result in the introduction (intentionally or unintentionally) of IAS from one location to another (Hulme et al. 2008; Essl et al. 2015; Saul et al. 2017).

Throughout history, humans have been moving and transporting species around the world and some non-native species contribute to the UK economy. However, as a result of global transport, trade and recreation, the rate of unintentional introductions is increasing (Lambdon et al. 2008; Seebens et al. 2018).

Prevention is considered to be the most cost effective management measure for IAS compared to control or eradication. It is expensive and often infeasible to eradicate an IAS once it has become established, so prevention is the first line of defence to guard against the long term costs of control (Genovesi and Shine 2004; Barbour et al. 2013; Dunn and Hatcher 2015). Preventing the pathways of introduction and developing a framework to prioritise pathways for intervention measures is key (Hulme et al. 2008; McGeoch et al. 2016). Furthermore, once an IAS has arrived and is established, it is important to target pathways to prevent its spread (McGeoch et al. 2016).

According to the Convention on Biological Diversity (CBD), “efforts to identify and prevent unintentional introductions as well as decisions concerning intentional introductions should be based on the precautionary approach, in particular with reference to risk analysis” (Guiding principle 1). Therefore future risks of possible invasions should be addressed and managed using a method of prevention rather than reacting after introduction. A number of policies have emerged in an attempt to implement prevention measures; including the EU Regulation (1143/2014) on the prevention and management of the introduction and spread of IAS. In 2003, a Defra review recommended that there was a need for a more coordinated response to the threat of IAS across Great Britain. As a result, Great Britain Non-Native Species (GBNNS) Strategy was produced with a Programme Board and Non-Native Species Secretariat responsible for its application. The Strategy is intended to provide a guiding framework for national, regional and local initiatives helping to reduce the impact of IAS on sensitive and vulnerable habitats and species. Policies attempt to change/influence behaviour and promote best practice to prevent the spread of IAS, and disease in animals and plants.

Biosecurity is a key part of prevention and is a proactive approach to preventing the spread of IAS which requires individuals to undertake practical measures to ensure the risk of spreading IAS from one location to another is reduced. Biosecurity is a key activity within disease management but it is also recognised as key method to prevent the introduction and spread of IAS (Dunn and Hatcher 2015; Sikes et al. 2018). As it only takes a few individuals or plant fragments to establish a new population, it is important to remove/kill propagules by employing good biosecurity measures. Improving the actions of stakeholders and increasing awareness of biosecurity is key to achieving the goals and objectives of the CBD, the EU IAS Regulation and the Great Britain Non-Native Species Strategy.

Since the introduction of IAS is a result of human activities, and prevention and biosecurity requires changing behaviour, it is necessary to look at the human as well as biological dimensions of IAS management. These include knowledge (Eiswerth et al. 2011; Seekamp et al. 2016), attitudes (Prinbeck et al. 2011), experience (Collado et al. 2013; Hung and Jan 2015), risk perceptions (O'Connor et al. 1999; Drake et al. 2014) and other factors such as social norms and social networks (Nyborg et al. 2016). Understanding the human dimensions of IAS can help form successful management interventions that target the actions of stakeholders to minimise the impacts of IAS in the environment and generate support for these interventions (van Riper et al. 2019). There has been much development in the literature studying the role that human factors play in support and attitudes around IAS management, but less measuring the interventions for behaviour change. Interventions for IAS management include legislation, regulations, control and prevention. However, social impacts such as opposition, political and legal struggles, and conflict can arise from these interventions which are likely to influence their effectiveness (Vanclay et al. 2015; Crowley et al. 2017). Research in this thesis therefore applies an interdisciplinary approach and draws from a combination of biological, social and political science literature. Applying an interdisciplinary approach to the issue of IAS prevention allows for a diverse perspective on the research subject and advances dialogues between these disciplines. It is important to bring these fields together in order to understand what factors are necessary for achieving behaviour change, and explore wider drivers that influence behaviour change, in order to address the issues of biological invasions and achieve the goals of policy. The thesis adapts Ajzen's Theory of Planned Behaviour (1991) to understand the relationship between human dimensions, perceived behavioural control and intention to behave. The thesis takes a critical approach and evaluates the effectiveness of some of the existing interventions used to target human dimensions and behavioural control to increase intention to change behaviour in relation to IAS. The following sections critically analyse this literature and identify the research gaps which the findings from this thesis address.

The introduction will first introduce the invasion process, highlight the pathways for invasion and potential impacts that IAS pose (focusing on freshwater and marine environments), identify existing legislative instruments and finally, assess biosecurity best practice and human dimensions of IAS biosecurity. Finally, this introductory chapter will outline the research approach and objectives of the thesis.

1.1 The invasion process

In order to manage the impacts of biological invasions, it is important to understand the stages of invasion. For a non-native species to become invasive in a new environment, it must succeed through several stages; transfer, introduction/arrival, establishment and spread (Figure 1.1) (Lockwood et al. 2005; Blackburn et al. 2011; Hatcher et al. 2012). Propagules (the subpopulation of the potential IAS) can be transported from their native range and introduced to new environments via vectors (e.g. trade, travel, recreation) (Lockwood et al. 2005). Propagules may be transported and introduced intentionally or unintentionally. The mechanisms in which they are introduced include release, escape, contaminant, stowaway and corridor (Hulme et al. 2008; Essl et al. 2015). Species can also spread naturally, but this thesis focuses on IAS that are spread as a result of human activities, as defined by the EU IAS Regulation. For example, many marine invertebrates arrive as stowaways with ballast water or as ship fouling (Katsanevakis et al. 2013; Nunes et al. 2015), and aquaculture, fishing and leisure activities are collectively responsible for more than 40% of the introductions of aquatic species in Europe (Gallardo and Aldridge 2013b).

Establishment success of an IAS depends critically on the propagule pressure. Propagule pressure is a measure of propagule size (number of individuals introduced) and propagule frequency (the frequency with which propagules arrive in a new habitat) (Blackburn 2011). Higher propagule pressure increases the likelihood of establishment. Following establishment, the population may continue to spread and expand its geographical range (Lockwood et al. 2005; Simberloff 2009).

The management framework for invasions can be summarised in terms of prevention (of translocation and introduction), containment or eradication (upon introduction to prevent establishment), and mitigation (Dunn and Hatcher 2015). Prevention includes biosecurity measures and early-warning practices including horizon scanning, surveillance and risk assessment. Containment strategies also involve surveillance and monitoring, coupled with active intervention to eradicate or limit the spread of established populations. If novel hosts or parasites do become established, strategies focus on mitigation of their impact or the prevention of further spread, again involving biosecurity and population management. It is widely accepted that action taken at early stages of invasion or emergence – such as preventative biosecurity measures – are more cost-effective and more likely to succeed than are the options for control or mitigation that are available at later stages of the process.

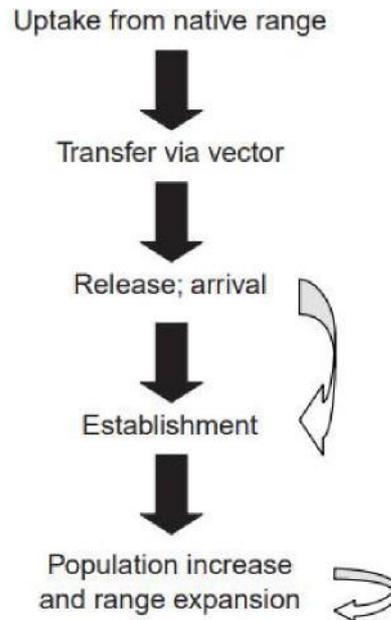


Figure 1.1 Stages of the invasion process, taken from Lockwood et al (2005). First non-native species are transported out of their natural range and released into a new location. Propagule pressure increases the likelihood of these species establishing a self-sustaining population and expanding the population and range beyond the initial establishment point. The transitions are represented by the black arrows and the white arrows illustrate propagule pressure increasing the likelihood of establishment.

As it only takes a few species or plant fragments to establish a new population, preventative measures such as biosecurity can act against propagule pressure to reduce both the population size and frequency of introduction (Dunn and Hatcher 2015). Once introduced into an ecosystem, dispersal of aquatic IAS may be easier in interconnected freshwater systems than the spread of their terrestrial counterparts (Moorhouse and Macdonald 2015). Biosecurity is the first line of defence against IAS and measures are designed to increase the likelihood of invasion failure between introduction and establishment (Figure 1.2) (Cock 2009; Dunn and Hatcher 2015). Biosecurity measures are important to reduce the likelihood of a species being introduced to a new country or region, as well as being important for reducing secondary spread of an invasive IAS. In this thesis I am exploring biosecurity to slow both the introduction and secondary spread of IAS.

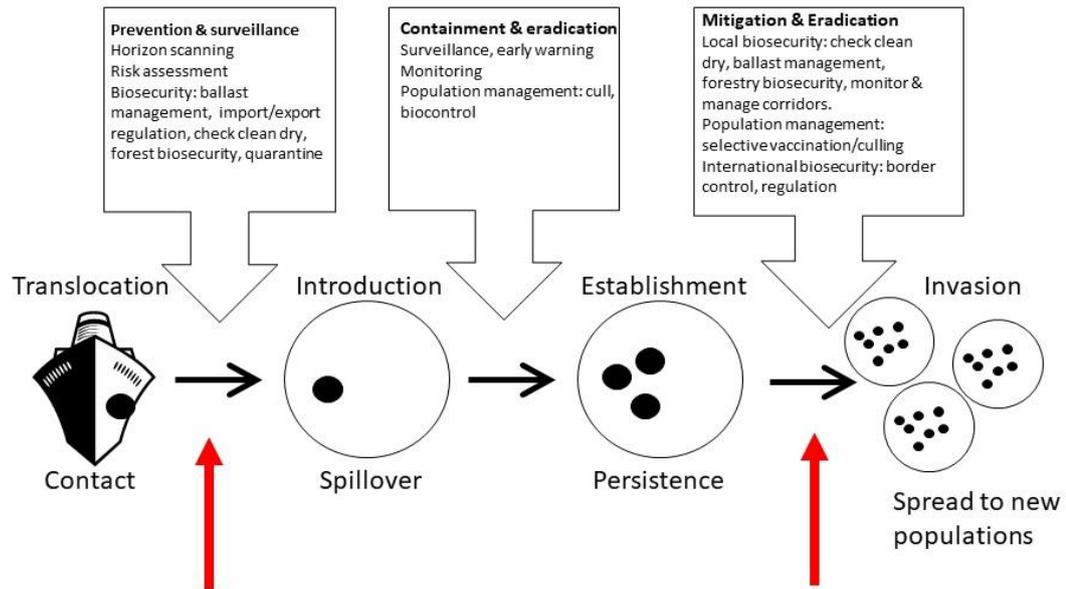


Figure 1.2 An outline of the invasion process for unintentional species introductions and the associated management framework (taken from Dunn and Hatcher (2015)). The invasion process involves a series of sequential stages (transport, introduction, establishment and spread) through which the stowaways need to transition to become successful invaders. The black arrows indicate the progression of individuals through the introduction process, with the boxes detailing the specific management framework for invasions, summarised in terms of prevention (of translocation and introduction), containment or eradication (upon introduction to prevent establishment), and mitigation (to limit further invasive spread) (Blackburn et al. 2011). Red arrows indicate where biosecurity measures are implemented. Prevention includes biosecurity measures and early-warning practices including horizon scanning, surveillance and risk assessment. Containment strategies also involve surveillance and monitoring, coupled with active intervention to eradicate or limit the spread of established.

Box 1.1 Terminology

Within the literature, terminology around IAS has been used inconsistently (Blackburn et al. 2011) with little consideration on how this impacts the implementation of management measures. However throughout this thesis, the term IAS is used consistently to describe species that have been moved into a new area and cause negative impacts, in accord with the EU definition.

Definitions and terms relating to biological invasions vary widely between countries and even between industries and are under debate. Terminology to describe species occurring in a location where they are not native include; non-indigenous, non-native, exotic, foreign and new (table 1). Species that are not native and cause negative impacts include; invasive, invasive non-native, alien, pest. The term 'invasive' is highly contested, but it usually refers to a self-sustaining population of an alien species that has negative impacts (environmental, economic or social) (Blackburn et al. 2011).

Table 1.1 Terminology used in this thesis

Term	Definition	Reference	Synonyms
Introduction	The movement by human agency, indirect or direct, of an alien species outside of its natural range (past or present). This movement can be either within a country or between countries or areas beyond national jurisdiction	CBD	
Establishment	The process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival	CBD	
Alien	Any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or micro-organisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce	EU IAS Regulation	Alien

Invasive Alien Species	An alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services	EU IAS Regulation (1143/2014) And CBD	Invasive species, invasive non-native species, pest
Pathway	The geographic route by which a species moves outside its natural range (past or present); the corridor of introduction (e.g. road, canal, tunnel); and/or the human activity that gives rise to an intentional or unintentional introduction	EU Strategy on IAS 2004	
Vector	The physical means or agent (i.e. aeroplane, ship) in or on which a species moves outside its natural range (past or present).	EU Strategy on IAS 2004	
Fomite	Inanimate objects capable of carrying organisms and hence transferring them between water bodies	(Merriam-Webster 2019)	Object

Researchers have identified the problematic nature of using terms such as ‘invasive’ in relation to human communities. There is much debate about the relationship between the language used regarding the term ‘invasive alien species’ and policy and public understanding of science and technology. Larson et al (2005) argue that Invasive species control has been frequently framed in militaristic language which is having an impact on government and scientists, where it is apparent in the series of campaigns and research studies about scientific communication and public understanding sponsored by governments in the United Kingdom (UK) and elsewhere.

The personification of ‘invasive species’ as foreigners or ‘others’ and ‘killers’ (Larson et al 2005) has had huge political debate in the United States where there are concerns about the link between invasive and foreign immigrants and visitors (Simberloff 2003). Smout (2003) suggested that terms such as ‘invasive’ and ‘alien’ should be replaced by ‘introduced’ and ‘naturalised’. In Great Britain, there was evidence of public rejection of the term ‘alien’ after a survey of public perception (Defra 2009). Since, the European term ‘alien’ was replaced by the term INNS/NNS which is now considered to be better understood than IAS within Great Britain (Defra 2018).

1.2 Pathways and impacts of IAS

Non-native species that are intentionally introduced are used in a broad range of industries, these include; agriculture, aquaculture, forestry, fisheries, horticulture and the pet trade (Hulme 2009). These species have the capability to accidentally escape into the wild and spread, causing huge negative economic, environmental and social impacts. There has been an increasing reliance on aquaculture to provide food security and economic development; this has led to an increase in the use of non-native species grown as food sources (Hewitt and Campbell 2007). However aquaculture is now considered to be one of the main pathways for intentional introduction in the aquatic environment as non-native species are introduced but can carry a known risk of escape or release into the wild (Roy et al. 2012). For example, in England and Wales *Pacifastacus leniusculus* (the signal crayfish) was introduced for aquaculture in the 1970s and 1980s from North America (Holdich et al. 2014). However after being introduced into aquaculture farms, the signal crayfish escaped into nearby watercourses where they established and spread and are now well established in England and Wales (Holdich et al. 2014). The spread of the signal crayfish has led to local extinctions of *Austropotamobius pallipes* (the white clawed crayfish) as the signal crayfish carries the oomycete *Aphanomyces astaci*, the causative agent of the crayfish plague which is lethal to the white clawed crayfish (Holdich et al. 2014). In large densities burrowing by the signal crayfish can also increase sediment load in rivers and cause bank collapses (Hogger 1986; Holdich et al. 2014). In 2010, activities set up to try and control and manage the signal crayfish and repair the damage caused in Great Britain were estimated to cost over £2 million per annum (Williams et al. 2010).

Many aquatic plants have also been intentionally introduced as ornamentals. For example *Ludwigia grandiflora* (water primrose) was originally introduced to Europe as an ornamental and water garden plant. However water primrose has since spread from initial introduction points and the plant now causes severe negative impacts, including out-competing native species and clogging waterways (Defra 2015). Due to the ecological and economic damage caused by water primrose in England, the species is now listed on Schedule 9 of the Wildlife and Countryside Act in England and Wales and it is now an offence to plant or otherwise grow these species in the wild. Currently the distribution of water primrose in Great Britain is limited. However, in 2010 it was estimated that the eradication and control costs caused by water primrose could potential reach a cumulative amount of £250 million for future control and removal depending on if the species becomes widespread (Defra 2015).

Other non-native species have been intentionally introduced for biological control of species that have already become invasive. However, in some cases these non-native species have had adverse impacts on the environment and native species and therefore become invasive themselves. For example *Rhinella marina* (cane toads) were first brought to Australia in 1935 in an attempt to control the native grey-backed cane beetle (*Dermolepida albobirtum*) and French's beetle (*Lepidiota frenchi*) (Griffiths and McKay 2007). However the toads have spread over more than a million square kilometres and have predated and depleted native fauna and reduced prey populations for native species; for example there is evidence of declines in native populations, for example *Varanus panoptes* (Argus monitor) populations dropped up to 90% (Griffiths and McKay 2007; Shine and Doody 2011; Doody et al. 2017). *Gambusia affinis* (the mosquito fish) is native to North America but has been introduced into many regions as a predatory biocontrol for mosquitos (Hatcher et al. 2012). However the mosquito fish can outcompete native species and also acts as a reservoir for helminth parasites, which is one of the most common infectious agents of humans in developing countries (Hatcher et al. 2012).

Some IAS are introduced unintentionally through pathways involving transport, trade, travel or tourism which have all accelerated the rate of species movements (Hulme 2009; Saul et al. 2017; Seebens et al. 2018). Pathways for the introduction and the secondary spread of IAS may be as a result of recreational activities such as gardening, hunting, hiking, fishing, and boating (Anderson et al. 2014; Tidbury et al. 2016), or trade and transport methods such as shipping and the release of ballast water, outside boats and on planes (Seebens et al. 2013). Propagules may become attached to objects (or fomites) such as traded goods, equipment, propellers and hulls of boats (Johnson et al. 2001; Reaser et al. 2008; Bacela-Spychalska 2016; Cole et al. 2019). Small species (small animals, plant fragments, pathogens) are also able to hitchhike in/on cargo, machinery, vehicles, timber and packaging material and can be carried in ballast water (Hulme 2009; Seebens et al. 2013).

For example, *Didemnum vexillum* (carpet sea squirt) fouls the hull of boats and is likely to have spread through the movement of marine vessels and aquaculture materials/equipment (Sambrook et al. 2014a). The carpet sea squirt can have negative ecological impacts on species diversity and abundance and it can form dense colonies; in the Great Britain it has recently posed a serious risk to aquaculture facilities as the fouling of equipment and stock increases maintenance and processing time, and can lead to poor health and high rates of mortality of stock (Griffith et al. 2009; Sambrook et al. 2014b; Bishop et al. 2015). Another key invader in freshwaters is *Dikerogammarus villosus* (killer shrimp) which is native to the Ponto Caspian region, and in the last 15 years has invaded many countries in Europe, including Great Britain in 2010. The killer shrimp has invaded through a combination of natural and human-mediated

dispersal via recreational and commercial shipping, which was facilitated by the opening of the Rhine-Main-Danube canal (Pöckl 2009). The killer shrimp has been found to cause the extinction of native amphipods and dramatically reduces the diversity and abundance of native fauna in an ecosystem (Madgwick and Aldridge 2011; Gallardo and Aldridge 2013a; Rewicz et al. 2014). *Dreissena polymorpha* (zebra mussel) is assumed to have been introduced into Great Britain through the shipping and recreational boating industry. The zebra mussel forms dense colonies and clogs water pipes at power plants, navigational locks and on other infrastructure in the aquatic environment; therefore the species not only causes environmental damage, but also raises health and safety concerns (Aldridge et al. 2004; Strayer 2009; Gallardo et al. 2012). Recreational boating and commercial boating in particular, is now considered by scientists, policy makers, management agencies as the primary means by which aquatic IAS are transported and spread (Johnson et al. 2001; Acosta and Forrest 2009; Murray et al. 2014; Tidbury et al. 2016)

Ballast water is one of the most significant pathways for unintentional marine invasion and evidence suggests that hundreds of species can be found in samples from an individual ship (Hulme 2009; Sylvester and MacIsaac 2010; Gallardo and Aldridge 2013b; Seebens et al. 2013). Not only do species found in ballast water have the potential to cause environmental damage, but some also have the potential to threaten human health. For example, *Vibrio cholerae*, the causative organism for cholera has been found transported in the ballast water of ships arriving at ports in North America (McCarthy and Khambaty 1994; Drake et al. 2005).

1.3 Managing biological invasions: policy and legislation

Pathway management is linked to policies and legislation that attempt to address the issues of IAS in the aquatic environment (Gallardo and Aldridge 2013a). A collection of different instruments are often used by governments to pursue a desired outcome. Policy instruments should form a coherent strategy to meet legislative requirements and goals from international agreements (Carter 2007). There are three important legal instruments (conventions) that recognise the negative impacts of IAS in the environment; the 1979 Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) at the European level and the 1992 CBD, and the 2017 Ballast Water Management (BWM) Convention at the global level. In this section I will introduce these agreements and relevant international and national legislation and policy.

According to the Bern Convention (1979) European countries must “strictly control the introduction of non-indigenous species”. Various European laws have been created to achieve

the goals of the Bern Convention, these include; the Habitats Directive 92/43/EEC, the Water Framework Directive (WFD) 2000/60/EC and the Marine Strategy Framework Directive (MSFD) 2008/56/EC, EU IAS Regulation (1143/2014). European law should then be transposed into national law. For example, in the UK the MSFD is transposed by the Marine Strategy Regulations 2010.

The CBD recognises that biological invasions are a human-mediated problem for the growing commitment to sustainable development. Aichi Biodiversity Targets for 2020 set global priorities, guidelines, collect information and help to coordinate international action on IAS. Aichi Biodiversity Target 9 of the CBD states that by 2020, “invasive alien species and pathways will be identified and prioritised, priority species will be controlled or eradicated, and measures will be in place to manage pathways to prevent their introduction and establishment.” Target 9 of the CBD identifies prevention as the preferable approach to managing IAS in an attempt to avoid the long-term costs that IAS can cause. The EU has agreed to meet the goals and objectives of the CBD and developed the EU Biodiversity Strategy 2011-2020 (UNEP 2011). The Biodiversity Strategy recognises that IAS pose a significant threat to achieving biodiversity in the EU and states that by 2020 IAS are “identified, priority species controlled or eradicated, and pathways managed to prevent new invasive species from disrupting European biodiversity” (Target 5). The Biodiversity Strategy recognises that (in exception to legislation concerning the use of alien and locally absent species in aquaculture) there was no dedicated comprehensive EU policy addressing the challenges posed by IAS. In January 2015 the EU Regulation on IAS (1143/2014) entered into force and provides a list of IAS of Union concern, of which the Regulation provides for a set of measures to be taken across the EU in relation to IAS included on the Union list. These measures follow the CBD three-stage hierarchical approach. The IAS Regulation focuses on identifying and managing the pathways and vectors by which IAS can be introduced and spread (horizon scanning) as required by the CBD. Member states (including the UK) are therefore bound by the IAS Regulation and are required to identify all of the potential pathways for IAS introduction, and to evaluate the significance of each route so that preventative action can be taken (Roy et al. 2014). Only after this has been undertaken can resources be prioritised, and measures implemented to minimise the risk from each pathway (Simberloff et al. 2013).

To also achieve the aims of the CBD and to reduce the risk of aquaculture escape or release into the wild, Council Regulation (708/2007/EC) on the use of alien and locally absent species in aquaculture aims to ensure there is adequate protection of aquatic habitats within European States. The Alien and Locally Absent Species in Aquaculture Regulations (2011) help

to implement Council Regulation 708/2007/EC in England and Wales, which also focuses on preventing the escape and spread of alien species outside of aquaculture.

Since the implementation of the Regulation to reduce the risk of escape from aquaculture, there is evidence to suggest that aquaculture-related introductions have declined, suggesting the effectiveness of regulation (Katsanevakis et al. 2013). The Regulations both promote prevention and apply a risk management approach to the introduction of alien species used in aquaculture. Aquaculture activities are also heavily monitored through disease regulation. For example, the Aquatic Animal Health Regulations (2009) implement the European Council Directive 2006/88/EC on Animal Health Requirements for aquatic animals and the prevention and control of certain diseases in aquatic animals in England and Wales. Whilst the Directive and Regulation focus on animal health, they promote the implementation of biosecurity practices to prevent the introduction and spread of disease which is instrumental to the success of aquaculture facilities. The aquaculture industry therefore stresses how prevention is key to reduce damage to the industry caused by pests and diseases (Essl et al. 2015).

The Ballast Water Management (BWM) Convention is a global international agreement that came into force in September 2017. The BWM Convention aims to reduce the impacts of marine IAS stowaways by regulating the treatment of ballast water and providing a comprehensive set of guidelines for Parties to implement. The BWM Convention is arguably one of the most substantial measures introduced to regulate an introduction pathway on environmental grounds (Essl et al. 2015). However the Convention is yet to be transposed into European and UK law.

Voluntary instruments aim to supplement, complement and can often replace direct government regulation, especially when targeting industry and sectors to address environmental problems (Gunningham and Sinclair 2002). Voluntary instruments can often be a flexible and cost-effective alternative to regulatory instruments and there has been a recent increase in voluntary instruments for managing pathways of IAS (Verbrugge et al. 2014; Hulme et al. 2017). Voluntary measures in the marine environment such as the International Maritime Organisation's (IMO) Guidelines for the Control and Management of Ships' Biofouling (IMO 2011) provides guidance on the control and management of ships' biofouling to minimise the transfer of aquatic IAS. Similarly, the European Code of Conduct on Recreational Boating and IAS (2016) aims to be compatible with the IMO Guidelines and targets the activities among recreational boaters as required by the CBD and Bern Convention to reduce the risk of introduction and spread of aquatic IAS (Council of Europe 2016a). The European Code of Conduct on Zoological Gardens and Aquaria (2016) aims to provide guidance on voluntary

measures to be adopted to strengthen the existing role of zoological gardens and aquaria in the conservation of biodiversity. The code of conduct focuses on, preventing the introduction and spread of IAS and related pathogens and diseases; promoting the need to increase awareness on biological invasions and; promoting IAS related research projects (Council of Europe 2016b). The GBNNS Strategy is the national framework to deal with IAS for Great Britain and contains the same three-stage approach as the CBD. The Strategy prioritises efforts to identify specific pathways of IAS for Great Britain and promotes the development of pathway action plans (voluntary measures) for priority pathways of introduction of IAS; so far these include the Zoos Pathway Action Plan and Great Britain Zoos Code of Practice and Guidance.

1.4 Human dimensions of IAS

Since IAS result from human activities, it is necessary to look at the human dimensions of IAS management (Hulme 2009; Ford-Thompson et al. 2015). Research on the social psychological processes that shape stakeholder opinions and behaviours are often utilised in conservation research as they can help agencies structure interventions in a way that motivates people to act more consistently (Schultz 2011; Cottet et al. 2015; Kemp et al. 2017).

The Theory of Planned Behaviour sets out to account for how a person's attitudes, subjective norms (social norms, social networks), and perceived behavioural control influence a person's intention to perform a behaviour (Ajzen 1991). This thesis uses this theory to provide a framework for examining attitudes and perceived behavioural control regarding behaviours that prevent the spread of IAS. In addition to attitudes are other human dimensions which can also influence behavioural intention. This thesis combines two of Ajzen's constructs (attitudes and subjective norms) and labels them individual and group dimensions. Individual dimensions include; knowledge, awareness, beliefs, attitudes, risk perceptions, experiences, values. Group dimensions include social networks, social norms, institutional trust and cultural background (Figure 1.3). This section will first introduce human dimensions of particular interest to this thesis and how they attempt to change behaviours. The following section will discuss how perceived behavioural control is also an important factor for predicting intention and behaviour.

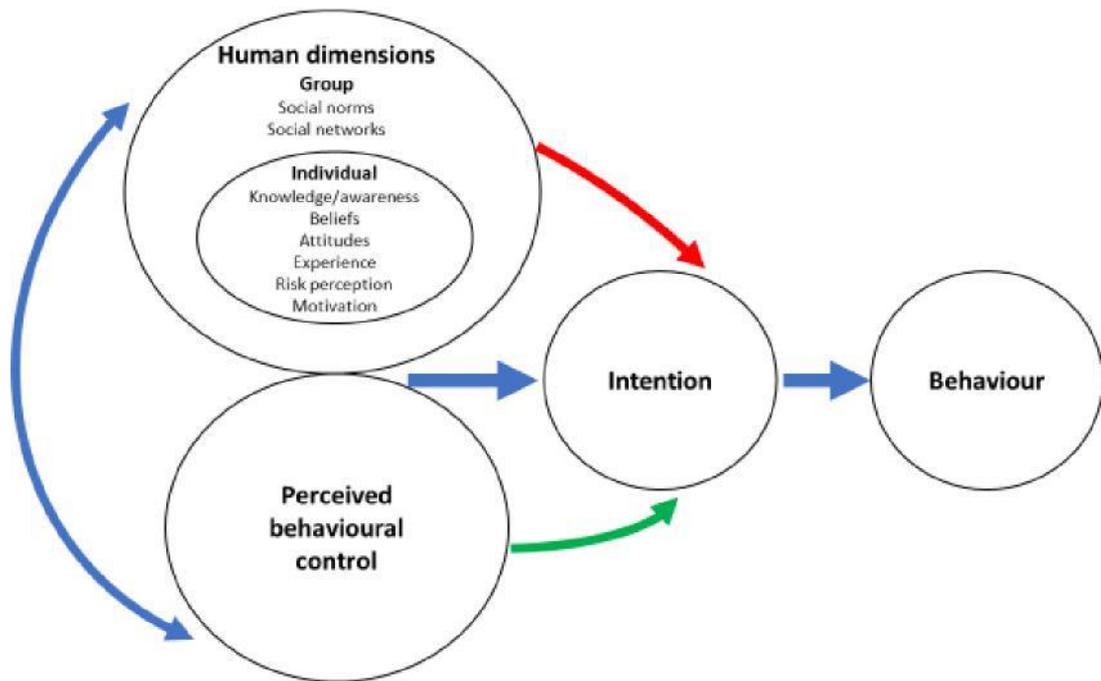


Figure 1.3 Conceptual framework to determine and change human behaviours (adapted from Ajzen's Theory of Planned Behaviour (1991)).

Behavioural intention is an indication of an individual's readiness to perform a given behaviour. It is based on human dimensions (individual and group) and perceived behavioural control. Human dimensions can shape and determine an individual's intention to behave and actual behaviour (red arrow). Human dimensions can either be at the individual level (knowledge, beliefs, attitudes, experience etc.) (inner circle) or group (subjective norms, social networks etc.) (outer circle). Perceived behavioural control can also determine intention and behaviour (green arrow) and is an individual's perceived ease or difficulty of performing the particular behaviour. If perceived behavioural control is strong, then it is expected that intention is favourable and the behaviour is produced. For example in the case of IAS, perceived behavioural control would be how easy or difficult it would be for the individual to carry out biosecurity cleaning measures.

1.4.1 Individual dimensions

1.4.1.1 Knowledge, awareness and attitudes

Knowledge and awareness are often seen as key to determine behaviour; if an individual does not know about an issue or the impacts of their actions, then they cannot be expected to change their behaviour. Knowledge is often acquired through experience or education and includes the gathering of facts, information, and skills about an issue. Awareness, is a broader

term and includes perceptions and emotions such as feelings and thoughts (Eiswerth et al. 2011). Eiswerth et al. (2011) found that knowledge and awareness of IAS was an important antecedent to participation in biosecurity behaviours to reduce IAS spread among the general public in Wisconsin. Similarly, Seekamp et al. (2016) in a study of water recreationists in North America found that knowledge and awareness of IAS was significantly related to prevention behaviours among recreational water users.

Attitudes are often linked to knowledge as it is assumed that as individuals become more knowledgeable about an issue, their attitude will become more positive, and thus in turn they will become more motivated to act toward the environment in more responsible ways (Hungerford and Volk 1990; Rothlisberger et al. 2010; McKenzie-Mohr and Schultz 2014). Fishbein and Ajzen (2010) define attitude as a person's positive or negative feelings about the outcome of performing a behaviour. Individuals with strong positive attitudes should therefore be more likely to engage in pro-environmental behaviours, therefore we must change attitudes in order to change behaviours. For example, Humair et al. (2014) found that horticulturalist's attitudes towards regulations to control IAS were supportive which in turn lead to participants reporting that they were also willing to engage in various voluntary actions to mitigate invasion risks from non-native ornamentals. Similarly, Wald et al. (2019) found that positive public attitudes toward IAS management lead to public support for conservation action.

Pro-environmental behaviour is described by Kollmuss and Agyeman (2002) as behaviour that consciously seeks to minimise the negative impact of one's actions on the natural and built world (e.g. minimise resource and energy consumption, use of non-toxic substances, reduce waste production). However, research has suggested that increases in knowledge and awareness do not always lead to pro-environmental behaviour (Hungerford and Volk 1990; Rothlisberger et al. 2010; McKenzie-Mohr and Schultz 2014), and similarly, attitudes do not always directly determine behaviour. In the literature this is considered the 'attitude-behaviour gap' (Kollmuss and Agyeman 2002). For example, despite high levels of awareness of regulations and supportive attitudes among horticultural industry managers towards regulations, Cronin et al. (2017) found that actual compliance with the regulations was low and many nurseries were stocking regulated IAS; perceived lack of enforcement, weak communication from government, and the lack of inclusion of the industry in the regulatory process were identified as constraints on compliance by the industry (Cronin et al. 2017). In an attempt to address these constraints, Cronin et al (2017) suggest that compliance could be improved by strengthening the partnership of industry and government which will ultimately increase trust and shift responsibility to the industry. It has been argued that single constructs

such as knowledge or attitudes cannot accurately predict behaviour, instead, trust, communication, enforcement and experience are just a few important additional determinants of attitude (Cronin et al. 2017; Wald et al. 2019).

1.4.1.2 Experience

Experience can increase familiarity of an issue and change attitudes through new experiences or information; experience is often an important focus of wildlife management research. Ford-Thompson et al. (2015) found that negative experiences (e.g. deer–vehicle collision, property damage) of the non-native Javan rusa deer (*Cervus timorensis*) in Royal National Park Australia, were associated with significantly more negative attitudes towards non-native species, whereas positive experience of deer had the opposite effect. Understanding how experience can determine attitudes that determine behaviour can help managers and policy makers in mitigating stakeholder conflict and achieving conservation objectives. In the field of climate change, Lorenzoni (2007) discovered that the degree of people’s engagement with climate change mitigating behaviours related to not just knowledge and beliefs, but also their experiences and lifestyle. Uncertainty and scepticism around global issues such as climate change can often be related to a lack of experience and familiarity with the issue (Lorenzoni et al. 2007). Similarly a lack of direct experience of the impact of IAS may also reduce familiarity with the issue and thus reduce positive attitudes towards biosecurity measures. On the other hand, an increase in experience can increase familiarity with an issue and therefore shape attitudes and develop long-term habits which can make it hard for new information and educational efforts to change behaviours (Lorenzoni et al. 2007). This is especially important in the case of IAS prevention as a person’s experience with IAS may directly influence their attitudes and determine whether they are supportive or not of biosecurity behaviour.

1.4.1.3 Risk perception

Experience has also been found to be a major influence on risk perceptions which can determine behaviour; experience can increase familiarity with a hazard and reduce perceptions of risk (Humair et al. 2014). Risk perception is defined by Slovic (1987, 2016) as how an individual thinks and feels about the risks they face in the context of limited and uncertain information. Individuals have different perceptions of risk; some will consider an activity/hazard as a high risk whilst others may not perceive any risk at all (Humair et al. 2014). Risk perceptions are particularly important because they can influence and are influenced by attitudes and knowledge and can also help predict behavioural intentions (O’Connor et al.

1999; Ballantyne and Packer 2005; Delabbio et al. 2005; Estévez et al. 2015). For example it is assumed that the more negative attitudes an activity evokes, the more risky it is perceived. Reduced risk perceptions around IAS through familiarity and experience can pose difficulties in IAS management especially where efforts are made to increase risk perceptions and encourage risk reducing behaviours such as biosecurity. Therefore, understanding how individuals perceive the risks associated with their activities can ultimately help to recommend future management measures (Dominicis et al. 2015).

Field researchers represent an important group of stakeholders who undertake activities in the field, such as surveying and sampling, which could potentially bring them into contact with IAS. In addition, field researchers come with significant environmental knowledge which has the potential to translate into good biosecurity practice. Field researchers' behaviour will also be influenced by individual risk perceptions of IAS and biosecurity, and awareness about the risks related to activities carried out in the field (Ballantyne and Packer 2005; Delabbio et al. 2005; Estévez et al. 2015). Experience of and exposure to IAS in the field may also significantly influence researchers' understanding of risk and so their biosecurity behaviour. Therefore it is important to investigate stakeholders' risk perceptions around IAS and biosecurity as these can help to predict behavioural intentions. **Therefore, in Chapter 2 I investigate researchers' awareness of IAS and perceptions of risk in relation to their field activities and whether awareness and risk perceptions influenced biosecurity behaviour.**

1.4.2 Group/societal dimensions

1.4.2.1 Social norms and social networks

Subjective norms refer to the belief that an important person or group of people will approve and support a particular behaviour. According to Ravis and Sheeran (2003), subjective norms can be made up of descriptive and social norms. Descriptive norms refer to real activities and behaviours that others are undertaking (Ravis and Sheeran 2003; Ham et al. 2015). On the other hand social norms are predominant behavioural patterns within a group that are supported by a shared understanding of acceptable actions, sustained through social interactions (Nyborg et al. 2016). Social norms therefore refer to the perception of other people's opinions on how the individual should behave (Prinbeck et al. 2011). Social norms rest on the assumption that people want to fit in with what most people do and what 'should be done' otherwise there is some form of punishment (Cialdini et al. 1990; Abrahamse and Steg 2013). Therefore social norms are often used to influence and encourage changes in behaviour (Abrahamse and Steg 2013). For example, within the plant and animal farming

sector, Mankad (2016) found that social norms were a strong predictor of biosecurity engagement as individuals were more likely to undertake biosecurity when they perceived a social consequence. Social norms also play an important role within the field of biological invasions, where different groups/activities within high-risk pathways (e.g. recreational boating, aquaculture) may have shared norms that influence behaviour (Mankad 2016). Nyborg et al. (2016) argue that (in addition to information and knowledge) social norms can spread through social networks when a community is connected and therefore individuals see and copy behaviour to fit in. Social networks are the friends, colleagues, neighbours and family of an individual, which can influence behaviour. It is important to keep in mind how social norms and social networks can determine behaviour, especially in the context of biosecurity and IAS, as there may be important social norms and networks among certain activities such as angling, recreational boating and aquaculture that will influence current behaviour and the likelihood of behaviour change (Kemp et al. 2017) .

1.5 Perceived behavioural control

Perceived behavioural control refers to people's perceptions of their ability to perform a given behaviour (Prinbeck et al. 2011; Ajzen 1991). Perceived behavioural control is therefore about making desired behaviours easier to do. If perceived behavioural control is positive then this can be a good indication of intention to perform the behaviour. Specific and local information about preventive behaviours through awareness campaigns, signs and images can increase perceived behavioural control (Prinbeck et al. 2011). Prinbeck et al. (2011) identified two behavioural control barriers among stakeholder groups when exploring attitudes and beliefs among stakeholders (gardeners, fishers, hunters and boaters) in relation to IAS prevention behaviours. The first barrier was a lack of information and a lack of understanding of what was being asked of stakeholders, as the advice to 'clean your boat' was vague. The second barrier identified by Prinbeck et al. (2011) was the difficulty to perform preventative behaviours as actions were often time consuming or impossible due to a lack of available infrastructure. Both barriers were also identified by Sutcliffe et al. (2017) when exploring views of biosecurity amongst stakeholders working in UK natural environments. These results highlight how important perceived behavioural control is as a factor in determining behaviour. Nonetheless, the Theory of Planned Behaviour predicts that the likelihood of an individual to behave in a certain way decreases if two or three of the constructs are unfavourable. Therefore a high level of perceived behavioural control in addition to positive attitudes and favourable social norms towards a desired behaviour is the best predictor for forming a behavioural intention.

1.6 Behaviour change interventions

Behavioural change interventions (information, campaigns, policy tools etc) are designed to target and change specified behaviour patterns by targeting human dimensions and perceived behavioural control in order to achieve behaviour change (Michie et al. 2011) (Figure 1.4). For example to address the attitude-behaviour gap, environmental training may be used as an intervention to develop skills necessary to undertake the behaviour required. A mixture of interventions have been used in the field of IAS, these include; information, campaigns, policy tools (through legislation and voluntary measures) and training. The following section will introduce behaviour change interventions of particular interest to this thesis and how they attempt to change behaviours.

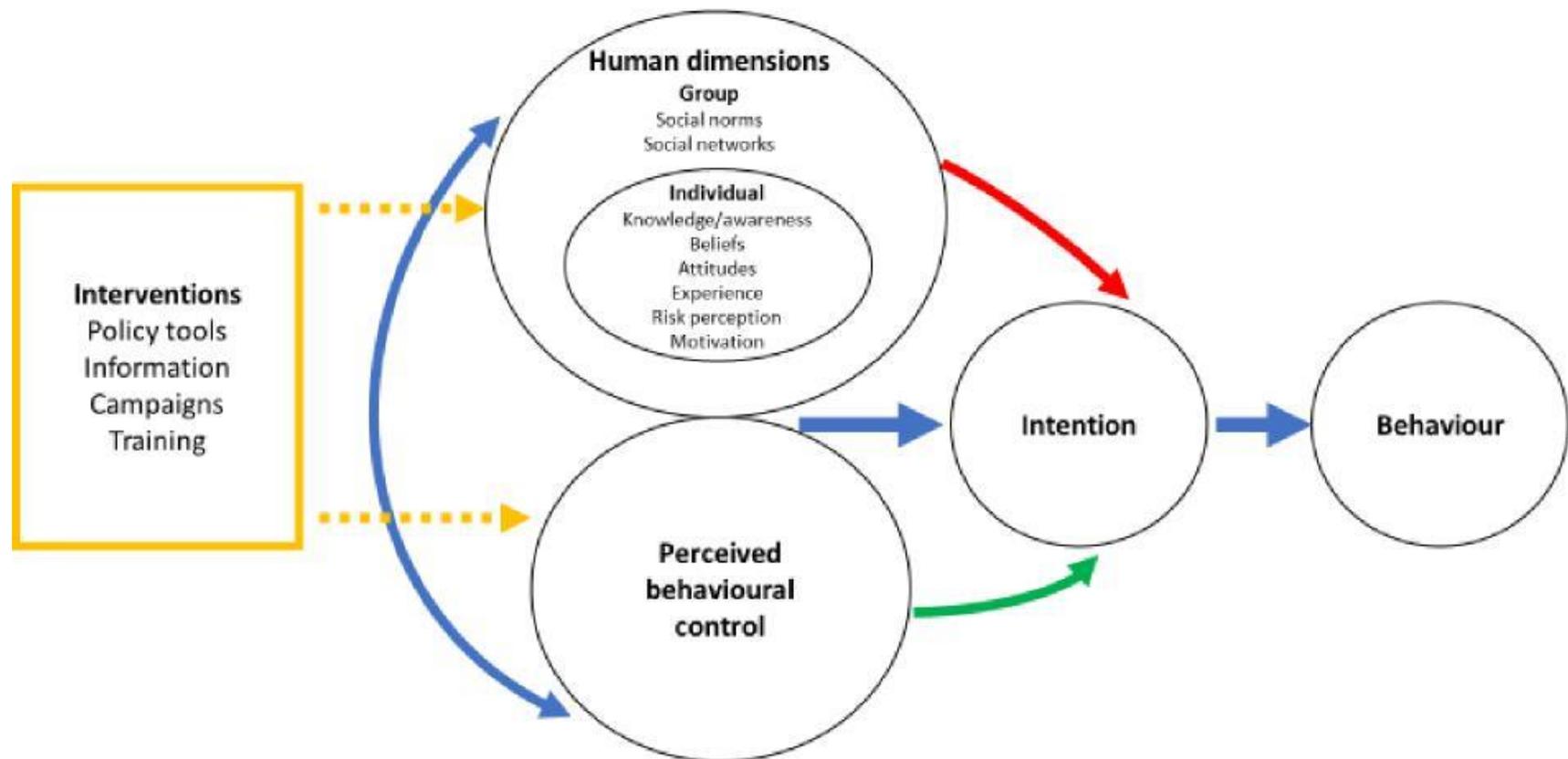


Figure 1.4 Interventions (yellow box) designed to increase intention and change specified behaviour patterns by targeting human dimensions and perceived behavioural control (yellow dash arrows)

1.6.1 Policy instruments (regulation and voluntary) as an intervention

Policy instruments set standards of what is acceptable behaviour for target groups (Carter 2007). Therefore policy instruments work at the group level to influence norms. Legislation (or law), is a legally binding agreement that attempts to achieve international goals at a regional, national or local level. Regulations are a binding legislative act which must be adopted and uses penalties and incentives in an attempt to influence the behaviour of stakeholders. Directives are also a legislative act that set out a goal which needs to be achieved, however each individual country (e.g. EU states) must devise their own laws to reach those goals. Both regulations and directives can often be an effective intervention approach for behaviour change (Michie et al. 2011). On the other hand, voluntary policy instruments (codes of conduct, strategies etc.) are not legally binding but also support behaviour change through education, provision of information and often individuals want to avoid regulation so follow the guidance of voluntary instruments (Carter 2007; Michie et al. 2011; Floerl et al. 2016).

Legislative and voluntary instruments designed to target pathways aim to reduce the rates of establishment of IAS, and ultimately the environment, economic and social impacts, by changing the behaviour of target groups (Carter 2007). Understanding the coherence of policies, their consistency and how they interact is considered to be one of the most important issues in environmental governance. Identifying synergies and conflicts between existing policies can help to determine their effectiveness on the ground (Carter 2007). Having inconsistent and incoherent policies can send confusing or conflicting messages to stakeholders and will ultimately limit the effectiveness of policy on the ground and reduce intention to change behaviour (Howlett and Rayner 2007; Owens and Driffill 2008; Schillo et al. 2017). There is yet to be any analysis to identify any gaps, weaknesses and inconsistencies in existing IAS policy instruments. **Therefore, in Chapter 3 I explore the coherence of marine biosecurity legislation for IAS at an international and national level.**

Whilst a combination of instruments exist in the UK that deal with IAS, currently no attempt has been made to understand the effectiveness of these policy instruments as behaviour interventions. Understanding the human dimensions (knowledge, attitudes and motivation) can help determine whether policy instruments are effective at encouraging positive behaviour change or whether there are other factors that influence motivation to undertake (or not undertake) biosecurity (Crowley et al. 2017). In addition, comparing two stakeholder groups can also help to determine why some instruments may be more effective than others depending on the group. Measuring the effectiveness of these policy instruments as

interventions can therefore help future development and design of policy. **Chapter 4 looks at the relationship between policy instruments and actual behaviour change. It will determine the effectiveness of existing policy and policy instruments on biosecurity behaviours among stakeholders within the marine environment through semi-structured interviews.**

1.6.2 Communication campaigns and information as an intervention

Public communication campaigns often focus on awareness (information-only/educational), instruction (step-by-step action strategies), or persuasion (why the individual should adopt the desired behaviour) (Dolan et al. 2010). Information-only campaigns have been criticised for assuming that increasing knowledge and information will translate into behaviour change (Connelly et al. 2014; van Riper et al. 2019). As McKenzie-Mohr (2000) asserts, educational campaigns raise awareness, but counter-intuitively that increased awareness/knowledge does not always result in long-term behavioural changes. For example, Rothlisberger et al. (2010) found that more than a quarter of respondents reported not always removing aquatic weeds when they saw them attached to their boat or trailer despite boating in states where outreach campaigns had promoted that behaviour. In contrast, instruction and persuasion campaigns take more of a social-marketing approach, focusing on providing stakeholders with illustrative step-by-step information and guidance on how to approach the problem rather than just information to increase awareness alone (McKenzie-Mohr 2000). Where awareness campaigns are information intensive, social marketing campaigns focus on barriers and benefits to behaviour change and are often focussed on developing certain skills among communities/activities (McKenzie-Mohr 2000). Within IAS management, campaigns focus directly on eliciting behaviour changes in individuals and communities (such as aquaculture, angling, recreational boating), rather than purely focusing on increasing awareness and changing attitudes (Michie et al. 2011). Therefore there has been a recent shift to instruction-oriented and persuasion campaigns (García-Llorente et al. 2011).

Biosecurity campaigns using the social marketing approach, have been adopted globally to promote voluntary behaviours by persuading people to change their behaviour. These include; the New Zealand *Check Clean Dry* campaign (launched in 2004) (www.mpi.govt.nz/travel-and-recreation/outdoor-activities/check-clean-dry), the United States' *Stop Aquatic Hitchhikers: Clean Drain Dry* campaign (2002) (www.stopaquatic hitchhikers.org), in Canada the *PlayCleanGo: Stop Invasive Species In Your Tracks* campaign (adopted in 2016) (<http://www.playcleango.org>); in England and Scotland the *Keep it Clean* campaign for the terrestrial environment (www.forestry.gov.uk/forestry/bee-h-a6tek3) which encourages individuals to take measures to reduce the spread of pests and disease. In the freshwater

environment, the *Check Clean Dry* (www.nonnativespecies.org/checkcleandry/index.cfm) biosecurity campaign in Great Britain targets the activities of water users in response to the outbreak of killer shrimp in 2010 in England.

The New Zealand *Check Clean Dry* campaign uses an instruction-orientated approach to increase awareness among water-users on the impacts of IAS and promote biosecurity measures (such as cleaning) to reduce the risk that their activities pose in spreading IAS. The New Zealand Government concluded that the campaign was so far successful in changing attitudes and changing behaviours of water users (NSMC 2010). Relying on self-reports, 98% of people who reported always following the *Check Clean Dry* advice and 95% of people who reported sometimes following the *Check Clean Dry* advice, had seen promotional items or received information from the campaign (NSMC 2010). In addition to this social research on reported behaviour, the spread of *Didymosphenia geminata* (rock snot) has appeared to have slowed and has not been reported in the North Island 5 years after the campaign began (Kilroy and Unwin 2011).

The Great Britain *Check Clean Dry* campaign is based on the New Zealand campaign and promotes simple steps for water users to take in order to prevent the introduction and secondary spread of IAS, these include;

- *Checking* equipment and clothing for living organisms, in particular areas that are damp or hard to inspect
- *Cleaning* and washing all equipment, footwear and clothes thoroughly
- *Drying* all equipment and clothing

Whilst the Great Britain campaign was initially targeted at freshwater users (anglers and freshwater recreational boaters) recent efforts to include users in the marine environment have been made in response to additional outbreaks (e.g. the outbreak of *Didemnum vexillum* in Holyhead marina). In addition to this, posters have been placed at borders and ports to remind stakeholders to undertake *Check Clean Dry* activities whilst abroad. Additional efforts have also been made to refine advice given to different groups of stakeholders in the freshwater environment, including to recreational boaters, anglers and the general public.

In 2014, Anderson et al. (2014) found that the UK *Check Clean Dry* campaign had only reached a small proportion of canoeists, with only 22% of respondents aware of the campaign. However, a more recent survey in the UK found that awareness of IAS amongst anglers and boaters had increased over the last 10 years, although awareness remains low amongst the public overall (67% general public aware compared to 87% of anglers and 83% of boaters)

(Defra 2018). However, the UK campaign was not intended to increase awareness alone, and also aimed to change behaviours. Anderson et al. (2014) found that canoeists who were aware of the *Check Clean Dry* campaign also exhibited better reported behaviours than those who were not (biosecurity hazard scores were 40% lower than those who were not) – suggesting that the campaign had been successful in bridging the gap between awareness and behaviour.

Previous research has found that aquatic plant fragments and animals were able to survive for at least 16 days in damp conditions (Anderson et al. 2015). Research found that several days of drying time were required to reach high mortality of a sample of IAS (Anderson et al. 2015); so whilst drying equipment is demonstrated to kill IAS propagules, it is slow to do so, therefore more rapid ways to induce mortality are needed. The use of hot water has been identified as a technique globally to support the “clean” process within ‘Check, Clean, Dry’ (Beyer et al. 2011; Stebbing et al. 2011; Rimmer et al. 2013; Anderson et al. 2015; Sebire et al. 2018). Research on seven high-impact aquatic IAS in the UK found that immersion in hot water for 15 minutes at 45°C caused high mortality (Anderson et al. 2015). However stakeholder interviews have highlighted many costs/barriers associated with uptake of biosecurity; these costs include issues around access to hot water and time to carry out cleaning and drying (Sutcliffe et al. 2017). Similar results have also been seen in the United States and Canada in finfish aquaculture, Delabbio et al. (2005) also found that of 8 biosecurity measures evaluated, only 3 were perceived by over 50% of respondents to be inclusively practical, effective and inexpensive in application. These barriers reduce an individual’s perceived behavioural control and therefore there is a need to establish refined advice based on what is practical in the field. **In Chapter 5, I test the effectiveness of hot water as a biosecurity treatment for key plant and animal IAS in Great Britain UK and develop practical biosecurity protocols that are effective and time efficient in field conditions.**

1.6.3 Environmental training as an intervention

While environmental education and environmental training are intimately connected, they are different. Environmental education focuses more on increasing knowledge, while environmental training focuses on developing the necessary skills to address the issue (Michie et al. 2011). Whilst instruction and persuasion campaigns often focus on providing stakeholders with illustrative step-by-step information and guidance to approach the problem, training focuses on delivering specialist skills information (McKenzie-Mohr 2000; Salas et al. 2006). Unlike campaigns which are often broad, training is often targeted at a specific audience and can either support campaigns or work independently. It is assumed that the

acquisition of knowledge, change in attitudes and the development of skills through training will lead to improved performance (Salas et al. 2006).

There are many different forms of training, these include; instructor-led training, coaching/mentoring, field training and online/e-Learning. E-Learning, or electronic learning, is a form of distance learning undertaken by an individual on a computer or other electronic device (Azeiteiro et al. 2015). There are many advantages to using e-Learning as an alternative to traditional face-to-face courses (flexibility, effective, cheap, scalability) (Bacelar-Nicolau et al. 2009). e-Learning is extremely flexible and can be undertaken at any time and place by the individual, therefore e-Learning can provide an effective alternative to face-to-face training. Research has demonstrated how online training can increase human dimensions such as awareness, change attitudes and risk perception and therefore prove effective for behaviour change (Azeiteiro et al. 2015). For example, online fire safety training is one of the most well-known types of training methods that employers utilise. In the case of fire training, the course attempts to increase awareness and increase perceptions of risk around fire safety, and provide step-by-step information on how to respond to fire situations (including the use of safety equipment such as fire extinguishers) (Harrington and Walker 2009). Behaviour change is the real purpose behind any training effort; therefore for training to be considered effective, a behavioural change should ideally be observed post-training (Gilpin-Jackson and Bushe 2007). e-Learning effectiveness can be evaluated in many forms including; learning outcome, transfer (application to practice), perceived learning, skills or competency, attitude, and satisfaction (Noesgaard and Ørngreen 2015).

To support the *Check Clean Dry* campaign and encourage changes in behaviour, e-Learning courses have been designed and are hosted by the GBNNSS (www.nonnativespecies.org/elearning/). These e-Learning courses are aimed at the activities undertaken by anglers, recreational boaters, environmental practitioners and contractors in an attempt to increase awareness, change risk perceptions and provide step-by-step information on how to undertake biosecurity. In addition to this, in 2015 the University of Leeds, Cefas, Environment Agency and the GBNNSS designed the *Better Biosecurity e-Learning course* targeting individuals conducting work activities or research (fieldwork) in marine, freshwater and terrestrial environments. Whilst there is much research on the benefits of e-Learning as a tool, which demonstrates the effectiveness of e-Learning on changing behaviour in other disciplines, the effectiveness of e-Learning has yet to be examined in the context of IAS and biosecurity. **In Chapter 6 I investigate the effectiveness of e-Learning training on awareness of IAS and/or biosecurity campaigns, risk perception of field activities accidentally spreading IAS, and on an individuals' self-reported cleaning and self-reported biosecurity practices.**

1.7 Aim and objectives of the thesis

Following the research gaps identified in the literature review, the primary research aim for the thesis is to understand the effectiveness of existing IAS interventions designed to change specified biosecurity behaviour patterns.

1.7.1 Objectives

The objectives are to:

1. Investigate the impact of human dimension such as knowledge and experience on risk perception and behaviour in relation to IAS and biosecurity
2. Explore the coherence of marine biosecurity policy for IAS at an international and national scale.
3. Investigate the effectiveness of existing policy and policy instruments as interventions for behaviour change by exploring the motivations of stakeholders for undertaking biosecurity in the marine environment
4. Investigate the effectiveness of hot water as a method of biosecurity for the Great Britain *Check Clean Dry* campaign
5. Evaluate the effectiveness of e-Learning as an intervention to increase awareness, risk perception and ultimately change behaviour

Figure 1.5 gives an overview of the thesis chapters in relation to the conceptual framework outlined in sections 1.4 and 1.5. The thesis is divided into two sections, the first looking at the human dimensions determining behaviour, the second reviewing the effectiveness of existing interventions that attempt to increase perceived behavioural control and intention to change behaviour.

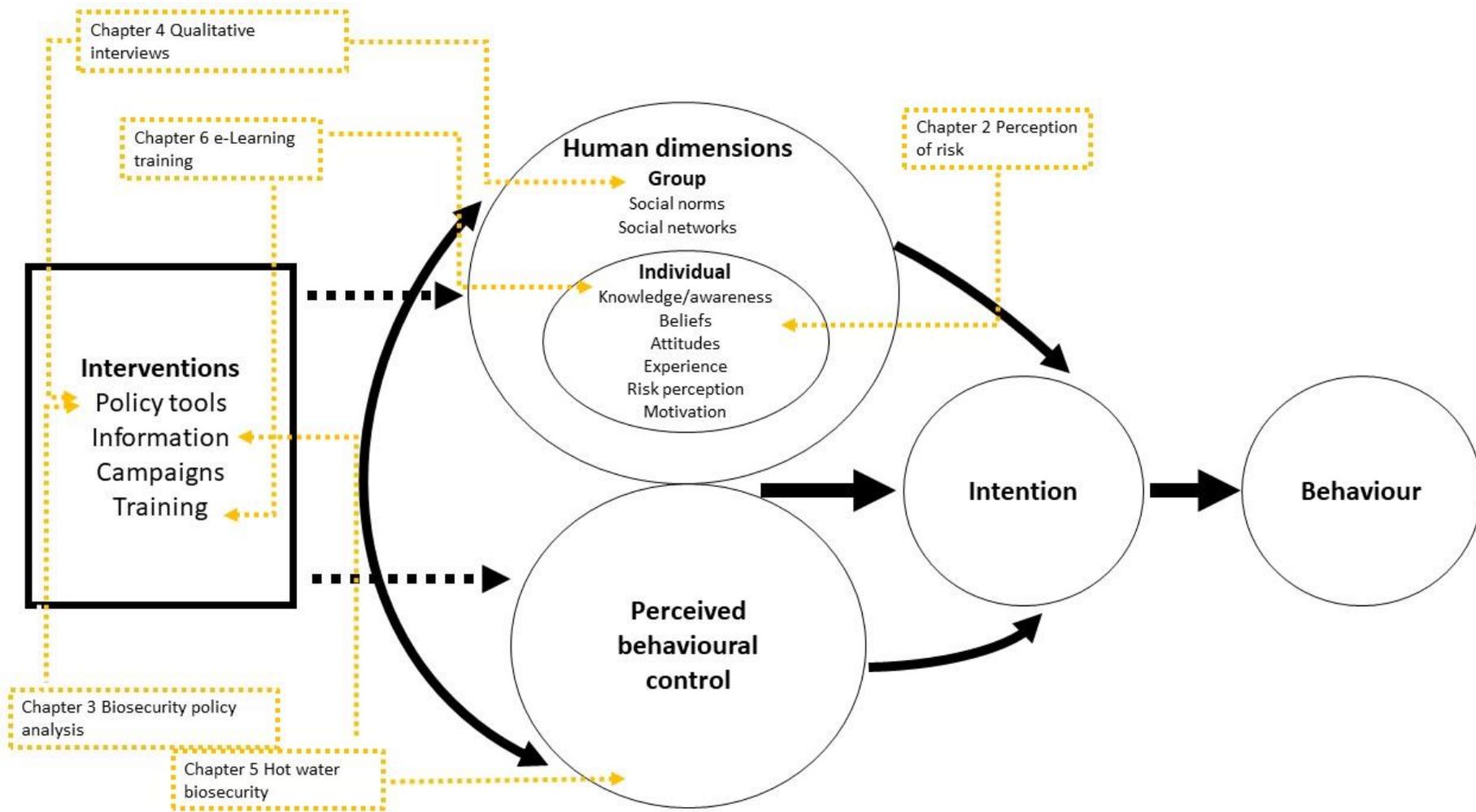


Figure 1.5 Conceptual framework to determine and change human behaviours, with related thesis chapters

1.7.2 Human dimensions determining behaviour

Biosecurity is key to preventing the introduction and spread of IAS. Researchers represent an important group of stakeholders who undertake activities in the field (e.g. sampling and surveying) that could potentially facilitate the spread of IAS. Researchers come with significant environmental knowledge which has the potential to translate into good biosecurity practice. Risk perceptions also influences a person's behaviour (O'Connor et al. 1999) and they themselves can be influenced by attitudes, beliefs and knowledge. Therefore understanding how researchers perceive the risks associated with their activities can help us determine drivers of behaviour, and ultimately help to recommend future management measures. **In Chapter 2 I use quantitative social research methods (online surveys) to collect baseline research on the risk perceptions and behaviours of a sample of field researchers in the UK. I investigate the impact of knowledge (academic discipline, exposure to INNS and information campaigns) on risk perception and biosecurity practice, and explore the impact of field experience and field activities on risk perceptions and biosecurity practice.**

1.7.3 Interventions for behaviour change

1.7.3.1 Policy

The marine environment poses a high risk of intentional and unintentional introduction of IAS through pathways and vectors of spread. Regulatory instruments are implemented from international to national level to address the impact of IAS on the environment, economy and society and to set a standard of what is acceptable behaviour. Whilst there has been a recent attempt to increase pathway-specific policies (e.g. European Code of Conduct on Zoological Gardens and Aquaria (2016)) there is yet to be any analysis that identifies any gaps, weaknesses and inconsistencies in existing IAS biosecurity policies. Applying a policy analysis to marine policy can help assess how global policy decisions are introduced into national systems. Policy analysis explores the coherence of policies and looks for consistencies and interactions between policies that are later translated into action on the ground. Policy coherence refers to the reduction of conflicts within and between policy areas (May et al. 2006; Nilsson et al. 2012; Kivimaa and Virkamäki 2014). Currently no analysis has been applied to the interaction between international and national policies that directly or indirectly relate to IAS management, in particular those that focus on biosecurity to prevent the introduction and accidental spread of IAS in the marine environment. **In Chapter 3 I undertake a policy analysis to identify current biosecurity legislation for the aquatic**

environment and explore the coherence of marine biosecurity policy for IAS at an international and national scale.

Policy instruments (regulatory and voluntary) are tools that are used to guide stakeholders, in an attempt to achieve the goals of international agreements or law (Hall 1993). A combination of regulatory and voluntary instruments are used to ultimately change the behaviour of target groups to address the introduction and mitigate the impacts of IAS in the marine environment. Further understanding of what influences an individual's motive to undertake (or not undertake) biosecurity measures may help to better inform future policy instruments. **In Chapter 4 I investigate the effectiveness of existing policy and policy instruments in changing behaviour by exploring the motivations of stakeholders to undertake biosecurity in the marine environment. Revealing motivations will also help to determine whether the current actions of stakeholders are achieving the goals of international agreements. Chapter 4 focuses on two case study groups in England and Wales which are identified as important pathways of introduction and secondary spread of IAS; the recreational boating sector and the shellfish industry, and uses a qualitative research method (semi-structured interviews) to assess the gaps in aquatic biosecurity management.**

1.7.3.2 Campaign advice

The UK *Check Clean Dry* biosecurity campaign promotes simple steps for water users to take in order to prevent the introduction and secondary spread of IAS. The use of hot water has been identified as a technique globally to support the 'clean' process within biosecurity campaigns (Beyer et al. 2011; Stebbing et al. 2011; Rimmer et al. 2013; Anderson et al. 2015; Sebire et al. 2018). Previous research has found that immersion in hot water for 15 minutes at 45°C caused 99% mortality among 7 high-impact aquatic IAS in the UK (Stebbing et al. 2011; Anderson et al. 2015). However, stakeholders have raised concerns and have highlighted issues with the current advised time to undertake biosecurity (Sutcliffe et al. 2017) which can ultimately reduce perceived behavioural control and reduce intention to change behaviour. Therefore it is critical to establish simple, cost effective biosecurity measures that are easy to perform. It is also important to refine the advice and test the advice in actual field conditions. **Therefore in Chapter 5 I refine the advice given by testing the efficacy of hot water treatment in actual field conditions, with a view to reducing the recommended time to clean equipment while still preventing spread. Refining the current advice and reducing the time taken to practice biosecurity may increase the adoption of good biosecurity practices, and help to achieve the goals of international agreements to prevent the introduction and spread of IAS.**

1.7.3.3 Training

Online training is increasingly being recognised as a cost-effective tool used to increase individuals' knowledge and awareness (education) around a particular issue and provide information (including step-by-step guidance) for individuals to develop the necessary skills to address the issue at hand to ultimately change behaviours (Michie et al. 2011). Since 2010, e-Learning courses have been designed to support the UK's *Check Clean Dry* campaign to increase awareness of IAS and the campaign among stakeholders as well as providing individuals with the skills to reduce the risk of accidentally spreading IAS in the marine, freshwater and terrestrial environment. e-Learning is available on the Great Britain Non-Native Species Secretariat website directed at anglers, boaters, environmental practitioners and site workers. In addition to these stakeholders, field researchers also represent an important group of individuals that pose a risk to the accidental spread of IAS as they conduct work activities or research (fieldwork) in the marine, freshwater and terrestrial environment. The *Better Biosecurity e-Learning course* designed by the University of Leeds, Cefas, Environment Agency and the GBNNS aims to achieve behaviour change by providing training to individuals. However, since investment in the *Better Biosecurity e-Learning course* in 2015, there has yet to be any evaluation of its effectiveness. **Chapter 6 is the first to evaluate the effectiveness of e-Learning as a tool to increase awareness, risk perception, self-reported biosecurity practice and cleaning behaviour in relation to IAS. Chapter 6 uses quantitative research methods (pre and post e-Learning online surveys) to evaluate the *Better Biosecurity e-Learning course* among field researchers (students and professionals within the UK) to determine whether e-Learning is an effective tool for behaviour change.**

1.8 Methodological approach

A stronger social scientific understanding of the interplay between anthropogenic and biological factors can help to close the so called 'knowledge-action gap' (Sharp et al. 2011; Selge et al. 2011; Humair et al. 2014; Marshall et al. 2016). Throughout this thesis, approaches from invasion science, social science and policy are brought together to address the issues of IAS in the aquatic environment, given the importance of human dimensions and behaviour in the management of IAS. This interdisciplinary approach incorporates methods and ideas from outside of the natural sciences in particular, in order to enable a better understanding of and improve policy, practice, and outcomes in relation to biosecurity. The focus of this study is on IAS prevention, which centres on individual's behaviour; this requires an understanding of the human dimensions of IAS management as well as biological science.

Interdisciplinary research is required in order to understand what influences a persons' behaviour in order to help future recommendations for policy and management.

1.8.1 Mixed methods

Due to the nature of the research aim, this thesis combines quantitative and qualitative approaches (mixed-methods). In this study a mixed methods approach allows for the creation and development of science informed biosecurity protocols using laboratory experiments, enables the collection and analysis of qualitative data in order to understand motivations of stakeholders to undertake biosecurity, and informs the design of social quantitative data collection methods to collect data on human dimensions (Figure 1.6). First, it was necessary to analyse related policy in order to determine the effectiveness of policy instruments as an intervention. Therefore, I undertook a policy analysis in order to assess how global policy decisions are introduced into national systems. Policy analysis allows the researcher to examine policy in-depth, analyse the implementation of policy and identify any inconsistencies and concerns which may impact implementation.

Online surveys were also used to gather data on knowledge, awareness, risk perceptions and behaviours among stakeholders. Social quantitative data collection and analysis allows for a larger sample of individuals to be measured over a longer period of time. Behaviour research is often conducted through self-reported measures such as surveys, which can sometimes lead to social desirability bias (Schwarz 1999). Social desirability bias is the tendency for individuals to present themselves in the best possible light, even if responding anonymously (Grimm 2010). For this reason, when creating online surveys, it was important to differentiate and ask questions about cleaning activities before asking questions about what individuals thought they did. Research suggests that there is a difference between what people think they do and what they actually do (Kollmuss and Agyeman 2002). Other limitations may exist within the research approach; there may have been self-selection bias where some individuals might have been more likely than others to complete the online survey and also agree to be contacted for the follow up survey (Andrews et al. 2003).

This thesis also used semi-structured interviews which are one of the main methods used for data collection in qualitative research (Saldaña 2013). Unlike set questionnaires, semi-structured interviews benefit from being loosely structured, allowing the interviewer to guide the discussion around topics of interest, but to remain sensitive to the fact that their initial understandings may change as the interview progresses (Morgan 2011). Semi-structured interviews were used to gather information on knowledge, attitudes and behaviours to

determine the effectiveness of existing policy and policy and to allow the researcher to investigate other factors that might motivate stakeholders' behaviour.

In order to refine the existing recommendations on hot water for the 'clean' process of the *Check Clean Dry* campaign, this thesis used laboratory experiments to refine current biosecurity recommendations. The aim of Chapter 5 was to reduce the time it takes to clean equipment for biosecurity, therefore undertaking experiments within a laboratory was the most effective method to scientifically test the effectiveness of the hot water method on mortality.

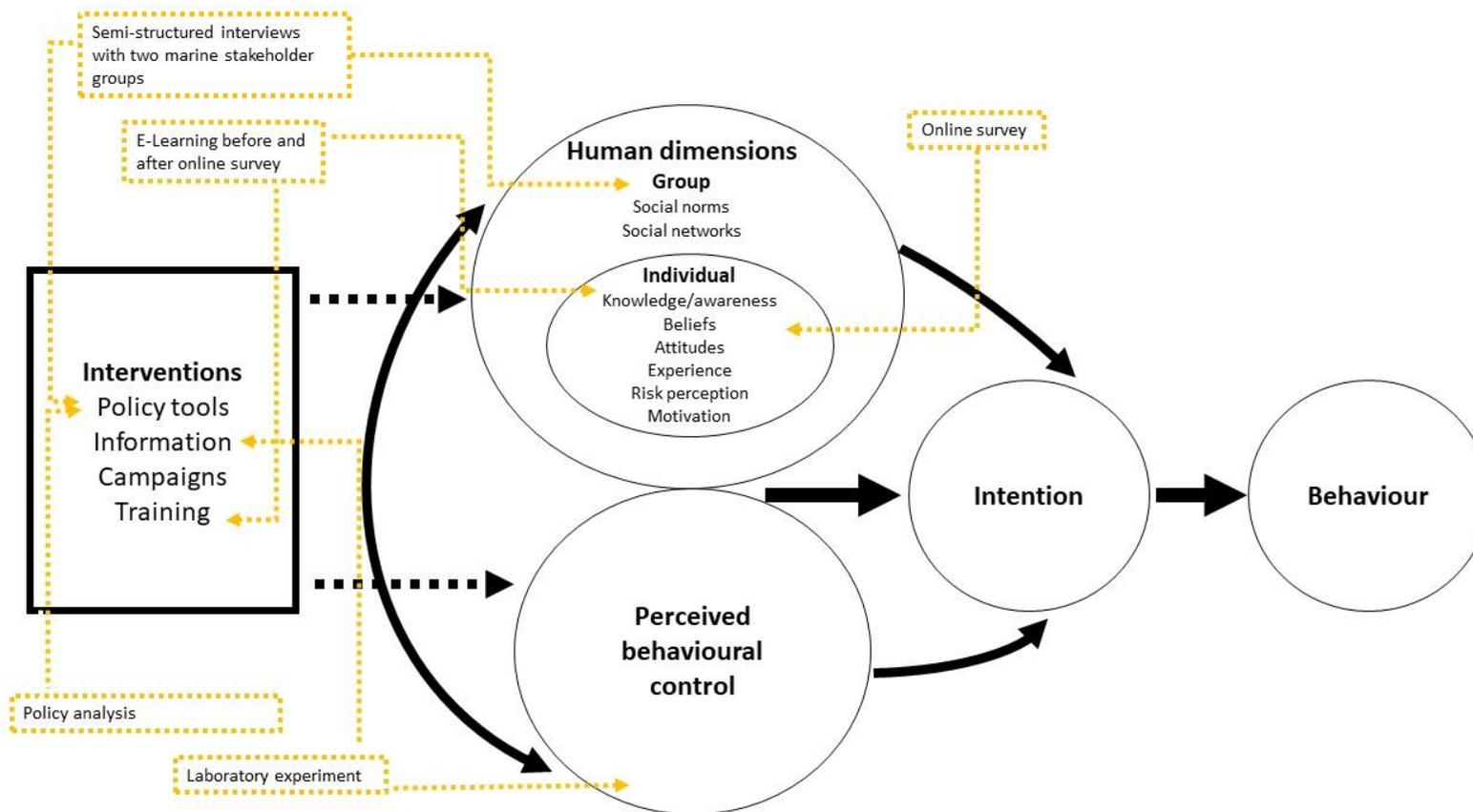


Figure 1.6 Conceptual framework to determine and change human behaviours, with integrated research methods. A mixed methods (both qualitative and quantitative data) approach was used to investigate different aspects of human dimensions on behaviour and develop an understanding of the effectiveness of existing IAS interventions designed to change specified behaviour patterns such as biosecurity.

1.8.2 Positionality and ethics

Positionality refers to the researcher's position and the effect of this on the interview process (Merriam et al. 2001; Sands et al. 2007). Positionality is influenced by a number of factors including personal characteristics (e.g. gender, affiliation, age) and personal experiences (e.g. beliefs, biases, preferences) (Sands et al. 2007; Berger 2015). For example, a respondent may be more willing to share their experiences with a researcher whom they perceive as sympathetic to their situation and if they are potentially helpful and in exchanging useful information in return (Berger 2015). The concept of positionality also incorporates ideas of power and class, and seeks to describe researcher identity in terms of an insider-outsider perspective, based on the researchers' relationship to the specific research setting and community (Mellor et al. 2014). A respondent may be less willing to share their experience with a researcher whom they cannot build a rapport with due to power dynamics or a researcher that has no experience or familiarity with the topic at hand. It was therefore important to design data collection in a way that minimises issues of positionality because this could potentially influence the responses, but also be aware of how positionality (such as gender and age) will influence the research too (Berger 2015).

Before interviewing it was important to remain transparent and honest about the research topic and with participants. As a researcher, I had existing contacts and previous knowledge into both the recreational sector and shellfish industry and this knowledge was useful for introductions and emailing participants (I had previously worked with some participants). Although I had previous experience with some individuals, I introduced myself as a PhD researcher/student from the University of Leeds so participants were made aware that this was for my PhD research, rather than a catch up. Before the interview process, I spoke about my research and the other chapters of my PhD. In some cases myself and participants that had met before would talk about past research/projects that we were part of. If I had not met the participant before, I asked them to talk about themselves and their interests/background which helped to show an interest and build a relationship with the individual, it also helped to identify similarities and identify any areas of shared interest. It was useful to have previous experience working and speaking with some participants as this meant that participants were more comfortable and open about their experiences.

During interviews I was self-reflective and I was aware of the information and experiences I spoke about, and the way this information was delivered, making sure that I was maintaining an empathic distance at the same time. Interviews were semi-structured to

allow for more of a discussion rather than a closed interview style. Speaking about previous experiences and identifying any shared contact connections with the individual allowed me to build a rapport with the respondents, this meant that individuals were able to open up about their experiences as knowing others that they worked with increased trust (Berger 2015). When interviewing participants from the shellfish industry, I would ask questions about their site and in some cases I was offered a site tour. Interviewing at their place of work opened up participants into talking about their business and the industry which would show an interest in their work. As a young female researcher, it was also important to position myself in a respectable manner but this involved changing my appearance dependent on the participant. For example, when meeting individuals from local or national government organisations, I would be more formally dressed, compared to individuals and sites on marinas or farms where I would be more casual and wear sensible footwear in the case of a site tour.

In order to minimise risk of harm (to myself and participants), ethical approval was sought from University of Leeds Ethics Review Committee (ref: BIOSCI 15-023; Appendix A) before data collection began. Ethical approval is especially important when considering issues related to data sharing and publishing and aims to provide assurance to participants around confidentiality and anonymity. The ethics application discussed key concerns around positionality (as discussed in Section 1.7.2), discussing sensitive topics, avoiding raised expectations, anonymity of respondents, obtaining free, prior informed consent and the possibility of work causing reputational damage.

Online surveys were used to collect data on awareness, risk perceptions and reported behaviour. The online survey included an introductory page which outlined the nature of the research including a statement ensuring that all individual information collected would be confidential and participants would remain anonymous; contact details were also provided. Participants were reminded that they could end the survey at any stage or ask for their answers to be withdrawn from the study at any point during data collection, although this was not requested by anyone.

For semi-structured interviews, participants were identified and approached via email to participate in the study at a time and place convenient for them. I maintained transparency with all informants about the purpose of my research and reminded participants at the beginning of each interview that I was not representing government (in particular Cefas) and all recorded interviews would be transcribed anonymously and the recordings deleted. All participants were asked to read the information sheet on the research and sign a consent form

at the time that the interview took place confirming they agreed to take part. Participants were reminded that they were able to end interviews at any stage and could ask for their answers to be withdrawn from the study at any point during data collection, although this was also not requested by anyone.

Risk assessment approval was also granted by the University of Leeds (Appendix B) for all fieldwork, including interviews and collecting biological samples for lab experiments.

1.9 References

Abrahamse W, Steg L. 2013. Social influence approaches to encourage resource conservation: A meta-analysis. *Glob Environ Chang* 23:1773–1785. doi: 10.1016/j.gloenvcha.2013.07.029

Acosta H, Forrest BM. 2009. The spread of marine non-indigenous species via recreational boating: A conceptual model for risk assessment based on fault tree analysis. *Ecol Modell* 220:1586–1598. doi: 10.1016/j.ecolmodel.2009.03.026

Ajzen I. 1991. The theory of planned behaviour. *Organ Behav Hum Decis Process* 50:179–211. doi: 10.1016/0749-5978(91)90020-T

Aldridge DC, Elliott P, Moggridge GD. 2004. The recent and rapid spread of the zebra mussel (*Dreissena polymorpha*) in Great Britain. *Biol Conserv* 119:253–261. doi: 10.1016/j.biocon.2003.11.008

Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD. 2015. Invaders in hot water: A simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biol Invasions* 17:2287–2297. doi: 10.1007/s10530-015-0875-6

Anderson LG, White PC, Stebbing PD, et al. 2014. Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLoS One* 9:1–10. doi: 10.1371/journal.pone.0092788

Andrews D, Nonnecke B, Preece J. 2003. Electronic Survey Methodology: A Case Study in Reaching Hard-to-Involve Internet Users. *Int J Hum Comput Interact* 16:185–210. doi: 10.1207/S15327590IJHC1602_04

Azeiteiro UM, Bacelar-Nicolau P, Caetano FJP, Caeiro S. 2015. Education for sustainable development through e-Learning in higher education: Experiences from Portugal. *J Clean Prod* 106:308–319. doi: 10.1016/j.jclepro.2014.11.056

Bacela-Spychalska K. 2016. Attachment ability of two invasive amphipod species may promote their spread by overland transport. *Aquat Conserv Mar Freshw Ecosyst* 26:196–201. doi: 10.1002/aqc.2565

Bacelar-Nicolau P, Caeiro S, Martinho AP, et al. 2009. e-Learning for the environment The Universidade Aberta (Portuguese Open Distance University) experience in the environmental sciences post-graduate courses. *Int J Sustain High Educ* 10:354–367. doi: 10.1108/14676370910990701

Ballantyne R, Packer J. 2005. Promoting environmentally sustainable attitudes and behaviour through free choice learning experiences: what is the state of the game? *Environ Educ Res* 11:281–295. doi: 10.1080/13504620500081145

Barbour JH, McMenamin S, Dick JTA, et al. 2013. Biosecurity measures to reduce secondary spread of the invasive freshwater Asian clam, *Corbicula fluminea* (Muller, 1774). *Manag Biol Invasions* 4:219–230. doi: 10.3391/mbi.2013.4.3.04

Berger R. 2015. Now I see it, now I don't: researcher's position and reflexivity in qualitative research. *Qual Res* 15:219–234. doi: 10.1177/1468794112468475

Beyer J, Moy P, De Stasio B. 2011. Acute upper thermal limits of three aquatic invasive invertebrates: Hot water treatment to prevent upstream transport of invasive species. *Environ Manage* 47:67–76. doi: 10.1007/s00267-010-9573-4

Bishop JDD, Wood CA, Lévêque L, et al. 2015. Repeated rapid assessment surveys reveal contrasting trends in occupancy of marinas by non-indigenous species on opposite sides of the western English Channel. *Mar Pollut Bull* 95:699–706. doi: 10.1016/j.marpolbul.2014.11.043

Blackburn TM, Pyšek P, Bacher S, et al. 2011. A proposed unified framework for biological invasions. *Trends Ecol Evol* 26:333–339. doi: 10.1016/j.tree.2011.03.023

Carter N. 2007. *The Politics of the Environment*. Cambridge University Press, Cambridge, UK

Chapple DG, Simmonds SM, Wong BBM. 2012. Can behavioural and personality traits influence the success of unintentional species introductions? *Trends Ecol Evol* 27:57–64. doi: 10.1016/j.tree.2011.09.010

Cialdini RB, Reno RR, Kallgren C. 1990. A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places. *J Pers Soc Psychol* 58:1015–1026. doi: 10.1037/0022-3514.58.6.1015

Cock MJW. 2009. Invasive alien species: a toolkit of best prevention and management practices. Oxford, UK

Cole E, Keller RP, Garbach K. 2019. Risk of invasive species spread by recreational boaters remains high despite widespread adoption of conservation behaviours. *J Environ Manage* 229:112–119. doi: 10.1016/j.jenvman.2018.06.078

Collado S, Staats H, Corraliza JA. 2013. Experiencing nature in children's summer camps : Affective, cognitive and behavioural consequences. *J Environ Psychol* 33:37–44. doi: 10.1016/j.jenvp.2012.08.002

Connelly NA, Lauber TB, Stedman RC. 2014. Reducing the Spread of Aquatic Invasive Species and Fish Pathogens in the Great Lakes: The Role of Anglers. New York, USA

Cottet M, Piola F, Le Lay YF, et al. 2015. How environmental managers perceive and approach the issue of invasive species: the case of Japanese knotweed s.l. (Rhône River, France). *Biol Invasions* 17:3433–3453. doi: 10.1007/s10530-015-0969-1

Council of Europe. 2016a. European Code of Conduct on Recreational Boating and Invasive Alien Species. Strasbourg

Council of Europe. 2016b. European Code of Conduct on Zoological Gardens and Aquaria and Invasive Alien Species. Strasbourg

Cronin K, Kaplan H, Gaertner M, et al. 2017. Aliens in the nursery: assessing the attitudes of nursery managers to invasive species regulations. *Biol Invasions* 19:925–937. doi: 10.1007/s10530-016-1363-3

Crowley SL, Hinchliffe S, McDonald RA. 2017. Invasive species management will benefit from social impact assessment. *J Appl Ecol* 54:351–357. doi: 10.1111/1365-2664.12817

Defra. 2015. The Great Britain Invasive Non-native Species Strategy. London, UK

Defra. 2018. Survey of Attitudes , Knowledge and Behaviour in Relation to Non-native Species. Shropshire, UK

Delabbio JL, Johnson GR, Murphy BR, et al. 2005. Fish disease and biosecurity: Attitudes, beliefs, and perceptions of managers and owners of commercial finfish recirculating facilities in the United States and Canada. *J Aquat Anim Health* 17:153–159. doi: 10.1577/H04-005.1

Dolan P, Halpern D, Hallsworth M, et al. 2010. *Mindspace: Influencing behaviour through public policy*. London, UK

Dominicis S De, Fornara F, Ganucci U, et al. 2015. We are at risk, and so what? Place attachment, environmental risk perceptions and preventive coping behaviours. *J Environ Psychol* 43:66–78. doi: 10.1016/j.jenvp.2015.05.010

Doody JS, Rhind D, Green B, et al. 2017. Chronic effects of an invasive species on an animal community. *Ecology* 98:2093–2101. doi: 10.1002/ecy.1889

Drake AR, Mercader R, Dobson T, Mandrak NE. 2014. Can we predict risky human behaviour involving invasive species? A case study of the release of fishes to the wild. *Biol Invasions* 17:309–326. doi: 10.1007/s10530-014-0729-7

Drake LA, Meyer AE, Forsberg RL, et al. 2005. Potential invasion of microorganisms and pathogens via “interior hull fouling”: Biofilms inside ballast water tanks. *Biol Invasions* 7:969–982. doi: 10.1007/s10530-004-3001-8

Dudgeon D, Arthington AH, Gessner MO, et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol Rev Camb Philos Soc* 81:163–82. doi: 10.1017/S1464793105006950

Dunn AM, Hatcher MJ. 2015. Parasites and biological invasions: Parallels, interactions, and control. *Trends Parasitol* 31:189–199. doi: 10.1016/j.pt.2014.12.003

Eiswerth ME, Yen ST, van Kooten GC. 2011. Factors determining awareness and knowledge of aquatic invasive species. *Ecol Econ* 70:1672–1679. doi: 10.1016/j.ecolecon.2011.04.012

Essl F, Bacher S, Blackburn TM, et al. 2015. Crossing Frontiers in Tackling Pathways of Biological Invasions. *Bioscience* 65:769–782. doi: 10.1093/biosci/biv082

Estévez RA, Anderson CB, Pizarro JC, Burgman MA. 2015. Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conserv Biol* 29:19–30. doi: 10.1111/cobi.12359

Fishbein M, Ajzen I. 2010. *Predicting and Changing Behaviour*. Psychology Press, New York, USA

- Floerl O, Inglis GJ, Diettrich J. 2016. Incorporating human behaviour into the risk–release relationship for invasion vectors: why targeting only the worst offenders can fail to reduce spread. *J Appl Ecol* 53:742–750. doi: 10.1111/1365-2664.12609
- Ford-Thompson AES, Snell C, Saunders G, White PCL. 2015. Dimensions of local public attitudes towards invasive species management in protected areas. *Wildl Res* 42:60. doi: 10.1071/WR14122
- Gallardo B, Aldridge DC. 2013a. Priority setting for invasive species management: Risk assessment of Ponto-Caspian invasive species into Great Britain. *Ecol Appl* 23:352–364. doi: 10.1890/12-1018.1
- Gallardo B, Aldridge DC. 2013b. The ‘dirty dozen’: socio-economic factors amplify the invasion potential of 12 high-risk aquatic invasive species in Great Britain and Ireland. *J Appl Ecol* 50:757–766. doi: 10.1111/1365-2664.12079
- Gallardo B, Errea MP, Aldridge DC. 2012. Application of bioclimatic models coupled with network analysis for risk assessment of the killer shrimp, *Dikerogammarus villosus*, in Great Britain. *Biol Invasions* 14:1265–1278. doi: 10.1007/s10530-011-0154-0
- García-Llorente M, Martín-López B, Nunes PA, et al. 2011. Analysing the Social Factors That Influence Willingness to Pay for Invasive Alien Species Management Under Two Different Strategies: Eradication and Prevention. *Environ Manage* 48:418–435. doi: 10.1007/s00267-011-9646-z
- Genovesi P, Shine C. 2004. European Strategy on invasive alien species. Council of Europe Publishing, Strasbourg
- Gilpin-Jackson Y, Bushe GR. 2007. Leadership Development Training Transfer: A Case Study Of Post-Training Determinants. *J Manag Dev* 26:980–1004. doi: 10.1108/02621710710833423
- Griffith K, Mowat S, Holt RHF, et al. 2009. First records in Great Britain of the invasive colonial ascidian *Didemnum vexillum* Kott, 2002. *Aquat Invasions* 4:581–590. doi: 10.3391/ai.2009.4.4.3
- Griffiths AD, McKay JL. 2007. Cane toads reduce the abundance and site occupancy of Merten’s water monitor (*Varanus mertensi*). *Wildl Res* 34:609–615. doi: 10.1071/WR07024
- Grimm P. 2010. Social desirability bias. *Wiley International Encyclopedia of Marketing*, Chichester, UK

- Gunningham N, Sinclair D. 2002. Voluntary Approaches to Environmental Protection: Lessons from the Mining and Forestry Sectors. OECD, Paris, France
- Ham M, Jeger M, Ivković AF. 2015. The role of subjective norms in forming the intention to purchase green food. *Econ Res* 28:738–748. doi: 10.1080/1331677X.2015.1083875
- Harrington SS, Walker BL. 2009. The Effects of Computer-Based Fire Safety Training on the Knowledge, Attitudes, and Practices of Caregivers. *J Contin Educ Nurs* 40:79–86. doi: 10.3928/00220124-20090201-07
- Hatcher MJ, Dick JTA, Dunn AM. 2012. Disease emergence and invasions. *Funct Ecol* 26:1275–1287. doi: 10.1111/j.1365-2435.2012.02031.x
- Hewitt CL, Campbell ML. 2007. Mechanisms for the prevention of marine bioinvasions for better biosecurity. *Mar Pollut Bull* 55:395–401. doi: 10.1016/j.marpolbul.2007.01.005
- Hogger JB. 1986. Aspects of the introduction of “signal crayfish”, *Pacifastacus leniusculus* (Dana), into the southern United Kingdom. 1. Growth and survival. *Aquaculture* 58:27–44. doi: 10.1016/0044-8486(86)90154-7
- Holdich DM, James J, Jackson C, Peay S. 2014. The North American signal crayfish, with particular reference to its success as an invasive species in Great Britain. *Ethol Ecol Evol* 26:232–262. doi: 10.1080/03949370.2014.903380
- Howlett M, Rayner J. 2007. Design Principles for Policy Mixes: Cohesion and Coherence in ‘New Governance Arrangements’ *Policy Soc* 26:1–18. doi: 10.1016/S1449-4035(07)70118-2
- Hulme PE. 2009. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *J Appl Ecol* 46:10–18. doi: 10.1111/j.1365-2664.2008.01600.x
- Hulme PE, Bacher S, Kenis M, et al. 2008. Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *J Appl Ecol* 45:403–414. doi: 10.1111/j.1365-2664.2007.01442.x
- Hulme PE, Brundu G, Carboni M, et al. 2017. Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *J Appl Ecol* 55:92–98. doi: 10.1111/1365-2664.12953

- Humair F, Kueffer C, Siegrist M. 2014. Are non-native plants perceived to be more risky? Factors influencing horticulturists' risk perceptions of ornamental plant species. *PLoS One* 9:e102121. doi: 10.1371/journal.pone.0102121
- Hung T, Jan LF. 2015. The Effects of Recreation Experience, Environmental Attitude, and Biospheric Value on the Environmentally Responsible Behaviour of Nature-Based Tourists. *Environ Manage* 193–208. doi: 10.1007/s00267-015-0488-y
- Hungerford HR, Volk TL. 1990. Changing Learner Behaviour through Environmental Education. *J Environ Educ* 21:8–21. doi: 10.1080/00958964.1990.10753743
- IUCN. 2019. Invasive Species. <https://www.iucn.org/theme/species/our-work/invasive-species>. Accessed 22 Apr 2019
- Johnson LE, Ricciardi A, Carlton JT. 2001. Overland Dispersal of Aquatic Invasive Species: A Risk Assessment of Transient Recreational Boating. *Ecol Appl* 11:1789–1799. doi: 10.2307/3061096
- Katsanevakis S, Zenetos A, Belchior C, Cardoso AC. 2013. Invading European Seas: Assessing pathways of introduction of marine aliens. *Ocean Coast Manag* 76:64–74. doi: 10.1016/j.ocecoaman.2013.02.024
- Kemp C, van Riper CJ, BouFajreldin L, et al. 2017. Connecting human–nature relationships to environmental behaviours that minimize the spread of aquatic invasive species. *Biol Invasions* 19:2059–2074. doi: 10.1007/s10530-017-1418-0
- Kettunen M, Genovesi P, Gollasch S, et al. 2009. Technical support to EU strategy on invasive alien species (IAS) - Assessment of the impacts of IAS in Europe and the EU (final module report for the European Commission). Brussels, Belgium
- Kilroy C, Unwin M. 2011. The arrival and spread of the bloom-forming, freshwater diatom, *Didymosphenia geminata* in New Zealand. *Aquat Invasions* 6:249–262. doi: 10.3391/ai.2011.6.3.02
- Kivimaa P, Virkamäki V. 2014. Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in Finland. *Environ Policy Gov* 24:28–41. doi: 10.1002/eet.1629
- Kollmuss A, Agyeman J. 2002. Mind the Gap : Why do people act environmentally and what are the barriers to pro- environmental behaviour? *Environ Educ Res* 8:239–260. doi: 10.1080/1350462022014540

- Lambdon PW, Pyšek P, Basnou C, et al. 2008. Alien flora of Europe: Species diversity, temporal trends, geographical patterns and research needs. *Preslia* 80:101–149
- Lockwood JL, Cassey P, Blackburn T. 2005. The role of propagule pressure in explaining species invasions. *Trends Ecol Evol* 20:223–228. doi: 10.1016/j.tree.2005.02.004
- Lorenzoni I, Nicholson-Cole S, Whitmarsh L. 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Glob Environ Chang* 17:445–459. doi: 10.1016/j.gloenvcha.2007.01.004
- Madgwick G, Aldridge DC. 2011. Killer Shrimps in Britain: hype or horror? *Br Wildl* 22:408–412
- Mankad A. 2016. Psychological influences on biosecurity control and farmer decision-making. A review. *Agron Sustain Dev* 36:1–14. doi: 10.1007/s13593-016-0375-9
- Marshall GR, Coleman MJ, Sindel BM, et al. 2016. Collective action in invasive species control, and prospects for community-based governance: The case of serrated tussock (*Nassella trichotoma*) in New South Wales, Australia. *Land use policy* 56:100–111. doi: 10.1016/j.landusepol.2016.04.028
- May PJ, Sapotichne J, Workman S. 2006. Policy coherence and policy domains. *Policy Stud J* 34:381–403. doi: 10.1111/j.1541-0072.2006.00178.x
- McCarthy SA, Khambaty F. 1994. International Dissemination of Epidemic *Vibrio cholerae* by Cargo Ship Ballast and Other Nonpotable Waters. *Appl Environ Microbiol* 60:2597–2601
- McGeoch MA, Genovesi P, Bellingham PJ, et al. 2016. Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. *Biol Invasions* 18:299–314. doi: 10.1007/s10530-015-1013-1
- McKenzie-Mohr D. 2000. Promoting Sustainable Behaviour : An Introduction to Community-Based Social Marketing. *J Soc Issues* 56:543–554. doi: 10.1111/0022-4537.00183
- McKenzie-Mohr D, Schultz PW. 2014. Choosing effective behaviour change tools. *Soc Mar Q* 20:35–46. doi: 10.1177/1524500413519257
- MEA. 2005. Ecosystems and human well-being: Synthesis. World Resource Institute, Washington, DC
- Mellor J, Ingram N, Abrahams J, Beedell P. 2014. Class matters in the interview setting? Positionality, situatedness and class. *Br Educ Res J* 40:135–149. doi: 10.1002/berj.3035

MEPC. 2011. Resolution MEPC.207(62)- 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. London, UK

Merriam-Webster. 2019. Fomite definition. <https://www.merriam-webster.com/dictionary/fomite>. Accessed 3 May 2019

Merriam SB, Johnson-Bailey J, Lee MY, et al. 2001. Power and positionality: Negotiating insider/outsider status within and across cultures. *Int J Lifelong Educ* 20:405–416. doi: 10.1080/02601370120490

Michie S, Stralen MM Van, West R. 2011. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement Sci* 6:42. doi: 10.1186/1748-5908-6-42

Moorhouse TP, Macdonald DW. 2015. Are invasives worse in freshwater than terrestrial ecosystems? *Wiley Interdiscip Rev Water* 2:1–8. doi: 10.1002/wat2.1059

Morgan A. 2011. *Investigating Our Experience in the World: A Primer on Qualitative Inquiry*. University of Tennessee Press, Tennessee, USA

Murray CC, Gartner H, Gregr EJ, et al. 2014. Spatial distribution of marine invasive species: Environmental, demographic and vector drivers. *Divers Distrib* 20:824–836. doi: 10.1111/ddi.12215

Nilsson M, Zamparutti T, Petersen JE, et al. 2012. Understanding Policy Coherence: Analytical Framework and Examples of Sector-Environment Policy Interactions in the EU. *Environ Policy Gov* 22:395–423. doi: 10.1002/eet.1589

Noesgaard SS, Ørngreen R. 2015. The effectiveness of e-Learning: An explorative and integrative review of the definitions, methodologies and factors that promote e-Learning effectiveness. *Electron J e-Learning* 13:278–290

NSMC. 2010. Check, Clean, Dry. [http://www.thensmc.com/dev/sites/default/files/Check%2CClean%2CDry FULL case study.pdf](http://www.thensmc.com/dev/sites/default/files/Check%2CClean%2CDry%20FULL%20case%20study.pdf). Accessed 21 Mar 2019

Nunes AL, Tricarico E, Panov VE, et al. 2015. Pathways and gateways of freshwater invasions in Europe. *Aquat Invasions* 10:359–370. doi: 10.3391/ai.2015.10.4.01

Nyborg K, Anderies JM, Dannenberg A, et al. 2016. Social norms as solutions. *Science* (80) 354:42–43. doi: 10.1126/science.aaf8317

- O'Connor RE, Bord RJ, Fisher A. 1999. Risk perceptions, General Environmental Beliefs, and Willingness to Address Climate Change. *Risk Anal* 19:461–471. doi: 10.1111/j.1539-6924.1999.tb00421.x
- Owens S, Driffill L. 2008. How to change attitudes and behaviours in the context of energy. *Energy Policy* 36:4412–4418. doi: 10.1016/j.enpol.2008.09.031
- Pöckl M. 2009. Success of the invasive Ponto-caspian amphipod *Dikerogammarus villosus* by life history traits and reproductive capacity. *Biol Invasions* 11:2021–2041. doi: 10.1007/s10530-009-9485-5
- Prinbeck G, Lach D, Chan S. 2011. Exploring stakeholders' attitudes and beliefs regarding behaviours that prevent the spread of invasive species. *Environ Educ Res* 17:341–352. doi: 10.1080/13504622.2010.542451
- Reaser JK, Meyerson LA, von Holle B. 2008. Saving camels from straws: How propagule pressure-based prevention policies can reduce the risk of biological invasion. *Biol Invasions* 10:1085–1098. doi: 10.1007/s10530-007-9186-x
- Rewicz T, Grabowski M, Macneil C, Karolina B. 2014. The profile of a 'perfect' invader – the case of killer shrimp, *Dikerogammarus villosus*. *Aquat Invasions* 9:267–288. doi: 10.3391/ai.2014.9.3.04
- Rimmer BG, Stebbing P, Longshaw M, Irving S. 2013. A review of potential methods to control and eradicate the invasive gammarid, *Dikerogammarus haemobaphes* from UK waters. Cefas, Weymouth, UK
- Rivis A, Sheeran P. 2003. Descriptive Norms as an Additional Predictor in the Theory of Planned. *Curr Psychol* 22:218–233. doi: 10.1007/s12144-003-1018-2
- Rothlisberger JD, Chadderton WL, McNulty J, Lodge DM. 2010. Aquatic Invasive Species Transport via Trailered Boats: What is Being Moved, Who is Moving it, and What Can Be Done. *Fisheries* 35:121–132. doi: 10.1577/1548-8446-35.3.121
- Roy HE, Bacon J, Beckmann B, et al. 2012. Non-native species in Great Britain, establishment, detection and reporting to inform effective decision-making. Defra, London, UK
- Roy HE, Peyton J, Aldridge DC, et al. 2014. Horizon scanning for invasive alien species with the potential to threaten biodiversity in Great Britain. *Glob Chang Biol* 20:3859–3871. doi: 10.1111/gcb.12603

- Salas E, Wilson KA, Priest HA, Guthrie JW. 2006. Design, Delivery, and Evaluation of Training Systems. In: Handbook of Human Factors and Ergonomics. John Wiley and Sons, Florida, pp 472–512
- Saldaña J. 2013. The Coding Manual for Qualitative Researchers. SAGE Publications, London, UK
- Sambrook K, Griffith K, Jenkins SR. 2014a. Review of Monitoring of Marine Non-native Species in Great Britain and Evaluation of Gaps in Data Dissemination. Bangor, Wales
- Sambrook K, Holt RHF, Sharp R, et al. 2014b. Capacity, capability and cross-border challenges associated with marine eradication programmes in Europe: The attempted eradication of an invasive non-native ascidian, *Didemnum vexillum* in Wales, United Kingdom. Mar Policy 48:51–58. doi: 10.1016/j.marpol.2014.03.018
- Sands RG, Bourjolly J, Roer-Strier D. 2007. Crossing cultural barriers in research interviewing. Qual Soc Work 6:353–372. doi: 10.1177/1473325007080406
- Saul WC, Roy HE, Booy O, et al. 2017. Assessing patterns in introduction pathways of alien species by linking major invasion databases. J Appl Ecol 54:657–669. doi: 10.1111/1365-2664.12819
- Schillo RS, Isabelle DA, Shakiba A. 2017. Linking advanced biofuels policies with stakeholder interests: A method building on Quality Function Deployment. Energy Policy 100:126–137. doi: 10.1016/j.enpol.2016.09.056
- Schultz PW. 2011. Conservation Means Behaviour. Conserv Biol 25:1080–1083. doi: 10.1111/j.1523-1739.2011.01766.x
- Schwarz N. 1999. Self-reports: How the questions shape the answers. Am. Psychol. 54:93–105
- Sebire M, Rimmer G, Hicks R, et al. 2018. A preliminary investigation into biosecurity treatments to manage the invasive killer shrimp (*Dikerogammarus villosus*). Manag Biol Invasions 9:101–113. doi: 10.3391/mbi.2018.9.2.04
- Seebens H, Blackburn TM, Dyer EE, et al. 2018. Global rise in emerging alien species results from increased accessibility of new source pools. PNAS 115:E2264–E2273. doi: 10.1073/pnas.1719429115

- Seebens H, Gastner MT, Blasius B. 2013. The risk of marine bioinvasion caused by global shipping. *Ecol Lett* 16:782–790. doi: 10.1111/ele.12111
- Seekamp E, McCreary A, Mayer J, et al. 2016. Exploring the efficacy of an aquatic invasive species prevention campaign among water recreationists. *Biol Invasions* 18:1745–1758. doi: 10.1007/s10530-016-1117-2
- Selge S, Fischer A, van der Wal R. 2011. Public and professional views on invasive non-native species – A qualitative social scientific investigation. *Biol Conserv* 144:3089–3097. doi: 10.1016/j.biocon.2011.09.014
- Sharp RL, Larson LR, Green GT. 2011. Factors influencing public preferences for invasive alien species management. *Biol Conserv* 144:2097–2104. doi: 10.1016/j.biocon.2011.04.032
- Shine R, Doody JS. 2011. Invasive species control: understanding conflicts between researchers and the general community. *Front Ecol Environ* 9:400–406. doi: 10.1890/100090
- Sikes BA, Bufford JL, Hulme PE, et al. 2018. Import volumes and biosecurity interventions shape the arrival rate of fungal pathogens. *PLoS Biol* 16:1–16. doi: 10.1371/journal.pbio.2006025
- Simberloff, D. 2003. Confronting invasive species: A form of xenophobia? *Biol Invasions* 5:179–92. doi: 10.1023/A:1026164419010
- Simberloff D (2009) The Role of Propagule Pressure in Biological Invasions. *Annu Rev Ecol Evol Syst* 40:81–102. doi: 10.1146/annurev.ecolsys.110308.120304
- Simberloff D, Martin J-L, Genovesi P, et al. 2013. Impacts of biological invasions: What’s what and the way forward. *Trends Ecol Evol* 28:58–66. doi: 10.1016/j.tree.2012.07.013
- Smout, T. C. 2003. The alien species in 20th-century Britain: Constructing a new vermin. *Landscape Research* 28 (1): 11–20. doi: 10.1080/01426390306527
- Slovic P. 1987. Perception of Risk. *Science* (80) 236:280–285. doi: 10.1126/science.3563507
- Slovic P. 2016. *The Perception of Risk*, 6th edn. Routledge, London, UK
- Stebbing P, Sebire M, Lyons B. 2011. Evaluation of a number of treatments to be used as biosecurity measures in controlling the spread of the invasive killer shrimp (*Dikerogammarus villosus*). Defra, Weymouth, UK

Strayer DL. 2009. Twenty years of zebra mussels : lessons from the mollusc that made headlines. *Front Ecol Environ* 7:135–141. doi: 10.1890/080020

Sutcliffe C, Quinn CH, Shannon C, et al. 2017. Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biol Invasions* 20:399–411. doi: 10.1007/s10530-017-1541-y

Sylvester F, Maclsaac HJ. 2010. Is vessel hull fouling an invasion threat to the Great Lakes? *Divers Distrib* 16:132–143. doi: 10.1111/j.1472-4642.2009.00622.x

Tidbury HJ, Taylor NGH, Copp GH, et al. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biol Invasions* 18:3277–3292. doi: 10.1007/s10530-016-1219-x

Tricarico E, Junqueira AOR, Dudgeon D. 2016. Alien species in aquatic environments: a selective comparison of coastal and inland waters in tropical and temperate latitudes. *Aquat Conserv Mar Freshw Ecosyst* 26:872–891. doi: 10.1002/aqc.2711

UNEP. 2011. The strategic plan for biodiversity 2011–2020 and the Aichi biodiversity targets. <https://www.cbd.int/sp/>. Accessed 13 Jul 2019

van Riper CJ, Browning MHEM, Becker D, et al. 2019. Human-Nature Relationships and Normative Beliefs Influence Behaviours that Reduce the Spread of Aquatic Invasive Species. *Environ Manage* 63:69–79. doi: 10.1007/s00267-018-1111-9

Vanclay F, Esteves AM, Aucamp I, Franks DM. 2015. *Social Impact Assessment: Guidance for assessing and managing the social impacts of projects*. International Association for Impact Assessment, North Dakota, USA

Verbrugge LNH, Leuven RSEW, van Valkenburg JLCH, van den Born RJG. 2014. Evaluating stakeholder awareness and involvement in risk prevention of aquatic invasive plant species by a national code of conduct. *Aquat Invasions* 9:369–381. doi: 10.3391/ai.2014.9.3.11

Wald DM, Nelson KA, Gawel AM, Rogers HS. 2019. The role of trust in public attitudes toward invasive species management on Guam: A case study. *J Environ Manage* 229:133–144. doi: 10.1016/j.jenvman.2018.06.047

Williams F, Eschen R, Harris A, et al. 2010. *The economic cost of invasive non-native species on Great Britain*. CABI, Oxford, UK

Chapter 2: Exploring knowledge, perception of risk and biosecurity practices among researchers in the UK: a quantitative survey

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2.1 Abstract

Accidental introduction and/or spread of Invasive Alien Species (IAS) can result from a range of activities including agriculture, transport, trade and recreation. Researchers represent an important group of stakeholders who undertake activities in the field that could potentially facilitate the spread of IAS. Biosecurity is key to preventing the introduction and spread of IAS. Risk perceptions are a fundamental component in determining behaviour, so understanding how researchers perceive the risks associated with their activities can help us understand some of the drivers of biosecurity behaviour in the field. The aim of this study was to investigate researchers' perceptions of risk in relation to their field activities and whether risk perceptions influenced behaviour. We gathered quantitative data on perceptions of risk and biosecurity practices using an online questionnaire. Only 35% of all respondents considered their field activities to pose some risk in terms of spreading IAS. Higher risk perception was found in those who undertook high risk activities or where IAS were known/expected to be present. However, whilst respondents with experience of IAS were more likely to report consciously employing biosecurity in the field, this did not translate into better actual biosecurity practices. Awareness of biosecurity campaigns did in fact increase perception of risk, perceived and actual biosecurity behaviour. However, there remains a disconnect between reported and actual biosecurity practices, including a lack of understanding about what constitutes good biosecurity practice. These findings should be used to improve targeted awareness raising campaigns and help create directed training on biosecurity practices.

2.2 Introduction

As the rate of invasion increases, there is a growing need to prevent ecological, economic and social impacts. Management and prevention of the introduction and/or spread of invasive alien species (IAS) is recognised as a global priority under the CBD and targets to achieve this have been transposed into recent EU legislation (EC Regulation 1143/2014). The EU

Regulation aims to address the problems IAS can create by targeting intervention measures; prevention, early detection and rapid eradication and management. Once an IAS has become established, eradication is frequently difficult, economically costly and has a low rate of success (Dunn and Hatcher 2015). Methods to prevent the introduction and spread of IAS are increasingly being recognised as the most cost effective means of reducing the impacts of IAS and are central to the EU regulation and the Invasive Non-Native Species Strategy for Great Britain (Perrings et al. 2002; Dunn and Hatcher 2015). Biosecurity measures cover all activities aimed at preventing the introduction and/or spread of IAS. Biosecurity measures to reduce the introduction and/or spread of IAS on fomites (e.g. clothing or equipment) can involve simple practices such as employing cleaning measures (Anderson et al. 2015; Dunn and Hatcher 2015).

In the UK, the Department for Environment, Food and Rural Affairs (Defra) launched the first invasive species specific biosecurity campaign '*Check Clean Dry*' in 2010, in response to the first reports of the invasive non-native killer shrimp (*Dikerogammarus villosus*). Freshwater ecosystems are disproportionately affected by IAS (Dudgeon et al. 2006) because of high anthropogenic activity including transport, recreation and research. The aim of the Check Clean Dry campaign was to reduce the risk of accidental introduction and spread of aquatic IAS by encouraging biosecurity best practice among water users. The campaign encourages people to check, clean and dry all equipment and clothing thoroughly to kill or remove any organisms that have the potential to survive while attached to equipment and be transported to a new location. Similarly, the '*Be Plant Wise*' campaign was also launched in 2010 by Defra and the Scottish Government. This campaign targets gardeners, pond owners and retailers, providing resources and advice on the damage caused by invasive aquatic plants and how they can be disposed of safely. Additionally, the Great Britain Non-Native Species Secretariat also offers free biosecurity e-Learning courses on how to plan and practice Check Clean Dry in the field for anyone who uses the environment for work or leisure (Defra 2015). Both campaigns and e-Learning resources aim to promote appropriate changes in perceptions and behaviours among individuals using the environment for recreation or research.

Researching stakeholder awareness, perceptions and practices in relation to biological invasions has been identified as a priority for the further development of targeted delivery of knowledge (Shackleton and Shackleton 2016). Researchers conducting fieldwork represent an important group of stakeholders in relation to IAS. They undertake activities in the field, such as surveying and sampling, that could potentially bring them into contact with IAS and facilitate their spread. However, while research has investigated the attitudes, risk perceptions and behaviours of anglers and recreational users (Anderson et al. 2014; Drake et al. 2014),

gardeners, hunters (Prinbeck et al. 2011), tourists and conservationists (García-Llorente et al. 2011) we have yet to turn the spotlight on ourselves.

Researchers come with significant environmental knowledge, in addition to that gleaned from broader biosecurity campaigns (Shackleton and Shackleton 2016), although that knowledge will be framed and determined by the disciplinary background of the researcher. This knowledge has the potential to translate into good biosecurity practice. However, behaviour in relation to biosecurity will be determined by more than just knowledge (disciplinary or otherwise) and will be influenced by individual risk perceptions to IAS and biosecurity, and awareness about the risks related to activities carried out in the field (Ballantyne and Packer 2005; Delabbio et al. 2005; Estévez et al. 2015). Risk perceptions are particularly important because they are influenced by attitudes, beliefs and knowledge and can help predict behavioural intentions (O'Connor et al. 1999). Direct experience has also been found to be a major influence on risk perception and action in relation to other environmental issues (e.g. climate change (Lorenzoni et al. 2007)) so experience of and exposure to IAS in the field may also significantly influence researchers' understanding of risk and so their biosecurity behaviour.

This study has two objectives: a) to investigate the impact of academic discipline, exposure to IAS and information campaigns (i.e. knowledge) on risk perception and biosecurity practice; and b) to explore the impact of field experience and activity on risk perceptions and biosecurity practice.

2.3 Methods

2.3.1 Survey design

An online questionnaire was created using Bristol Online Surveys software (<https://www.onlinesurveys.ac.uk/>) to gather information on knowledge, risk perceptions and biosecurity practices among researchers within the UK (Appendix C). A pilot study was conducted ($n=7$) to ensure the online questionnaire worked effectively and to reduce ambiguity or misinterpretation of the questions. This pilot data was not used in the overall analysis. The online questionnaire was conducted between 12th June 2015 and 31st July 2015 and was designed to take 15-25 minutes. Using a multiple start point snowball sampling strategy (Miller and Brewer 2003), invitation e-mails were sent to researchers with the request that they complete the online questionnaire and forward the invitation to their colleagues and research groups. Reminder emails were sent out weekly during the survey period to encourage people to complete the questionnaire. A total of 65

questionnaires were completed. The online questionnaire satisfied the University of Leeds' guidelines on ethical conduct (Ethics reference AREA 14-121) and all data was collected, stored and analysed anonymously. A definition of IAS was given at the start of the online questionnaire.

2.3.1.1 Demographic data

The first section sought two items of demographic data (gender and age) and the role of the respondent at their institution. Respondents could choose up to four disciplinary areas that best described their research/study.

2.3.1.2 Fieldwork

The second section gathered information about the locations where researchers had undertaken field research, both in the UK and overseas. Respondents could select more than one environment in which they carried out field activities. Respondents were asked to identify all the field activities they carried out (sampling, monitoring, conservation, etc), these results were used to determine their field experience to address objective b. Using polar questions (yes, no), all respondents were asked whether they used equipment when undertaking fieldwork.

2.3.1.3 Actual biosecurity practices

The third section of the questionnaire focused on actual biosecurity practices undertaken by respondents. Respondents who answered yes to using equipment in the field were asked further questions including which items they used, what the equipment came into contact with, as well as further questions relating to how often they used equipment and their cleaning practices. If individuals did not use equipment in the field they were forwarded onto the next section. Respondents were asked how often they checked, cleaned and dried equipment and modes of transport (including the tyres/wheels or boat hulls) before, after and between visits and again for the use of footwear and outerwear during field research. The term biosecurity was not used when individuals were asked about general cleaning procedures to avoid prejudice for questions later in the survey and to determine whether what individuals think, say and what they do are consistent. These data were used to generate a quantitative 'actual' cleaning numerical score for each individual in the analysis. Respondents were scored on cleaning equipment, vehicle tyres/wheels/hulls and footwear/outerwear before arriving on site, before departing a site and drying thoroughly in between uses. Responses were scored from 0-4 (e.g. never =0, rarely =1, sometimes = 2,

often=3, always= 4), each respondent was given a mean score for each variable (equipment, vehicle and footwear/outerwear) and then a combined overall mean score. The higher the score the better the actual biosecurity practice of the individual. Not all individuals completed all cleaning questions as many did not use equipment in the field and therefore did not receive a mean cleaning score for this variable; these individuals were given a mean score on the other two variables.

2.3.1.4 Awareness and perceptions of risk

Section four of the questionnaire investigated awareness of IAS issues and perceptions of risk of introducing/spreading IAS while undertaking fieldwork. Respondents were asked whether they considered their field activities to pose any risk in term of spreading IAS (yes or no). Respondents that answered yes were asked to estimate the risk their actions posed from low (1) to high (5). To measure exposure to IAS in the field, participants were asked whether they had ever carried out field activities in an area where they knew or suspected that IAS were present, participants were able to answer using yes or no.

Respondents were asked whether they were familiar with any biosecurity campaigns (yes or no) and could give further detail to what campaigns they had heard of.

2.3.1.5 Perceived biosecurity

The final section of the questionnaire asked all respondents to self-report on whether they consciously employed biosecurity measures in the field regardless of awareness of IAS and familiarity with campaigns/training (yes/no). Self-reports have been argued to be reflections of an individuals' beliefs or perceptions about behaviour (Corral-Verdugo 1997). Therefore, asking individuals to self-report enabled investigation of perceived biosecurity against actual reported cleaning (biosecurity) practices.

2.3.2 Statistical analysis

All statistical analyses were carried out in R version 3.2.1 (R Core Team 2015) with $\alpha = 0.05$. We grouped our explanatory variables into two categories: knowledge (academic discipline, exposure to IAS, and familiarity with biosecurity campaigns) and experience (sampling and aquatic activity), and tested for the influence of each category on risk perception (whether an individual perceived their activity to pose a biosecurity threat), reported biosecurity (whether respondents consciously employed biosecurity), and actual biosecurity scores, including relevant two-way and three-way interactions. Models investigating risk perception and perceived biosecurity were investigated using a binomial error structure.

Models investigating actual biosecurity were investigated using a Gaussian error structure; data were normally distributed.

To identify significant explanatory variables, GLMs were simplified to minimum adequate models (MAMs) following Crawley (2007), discarding terms whose exclusion from the model did not significantly increase deviance. χ^2 and F tests of significance were employed for binomial and Gaussian models respectively.

2.4 Results

2.4.1 Return rate and demographics

The online questionnaire was completed by 65 respondents from a total of 12 different universities and research institutes, all based within the UK. A range of age groups were represented with most respondents aged between 26 and 35 (43%), with the second largest age group aged between 36 and 45 (20%). A smaller number of respondents were aged under 25 (12%) and the final quarter of respondents were aged over 46. A wide range of roles were represented (Figure 2.1) with most respondents identifying as PhD students (29.2%), as post-doctoral researchers (13.8%) and lecturers (12.3%).

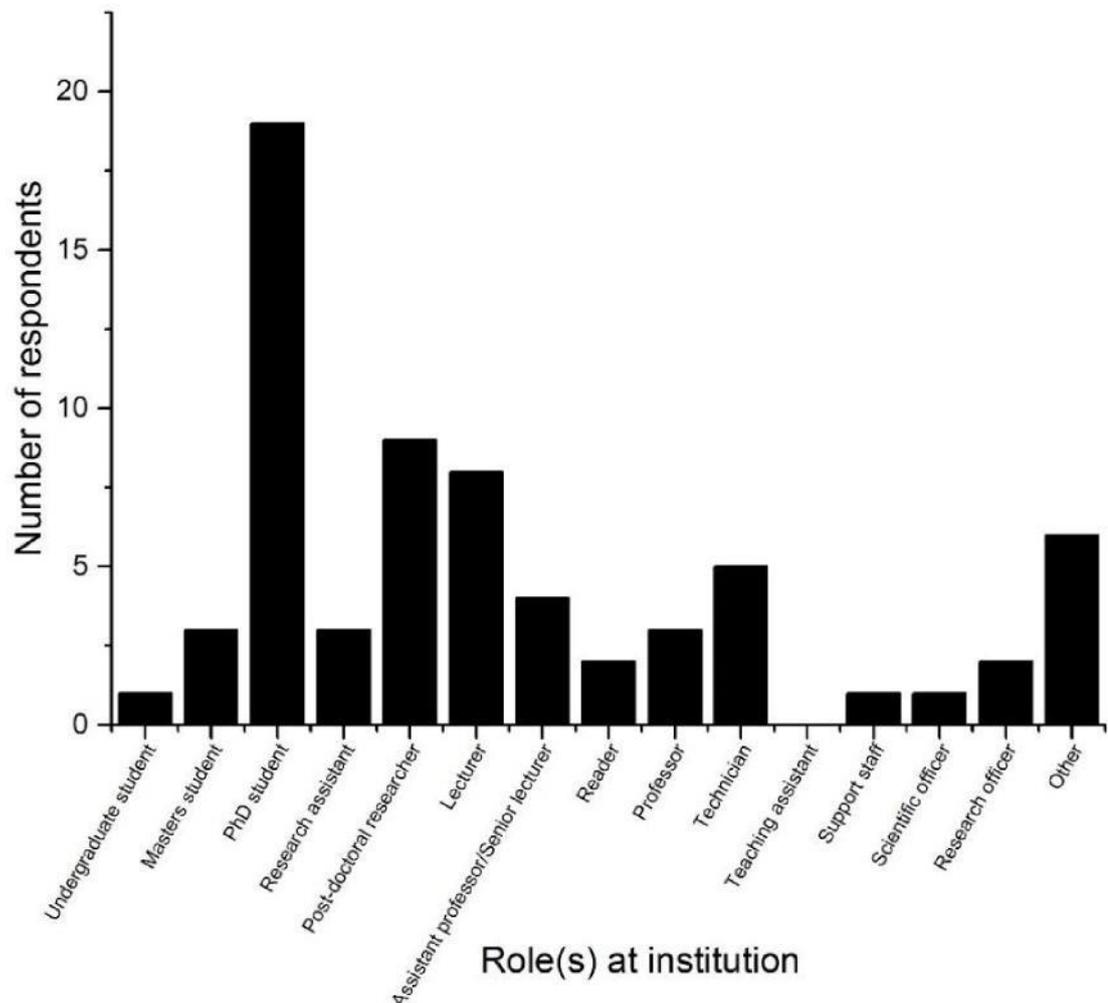


Figure 2.1 Roles identified by researchers. A range of roles were represented, with most researchers identifying as PhD students ($n = 19$)

Each respondent could select up to four disciplinary areas to describe their study/research or teaching. The most frequently selected discipline was ecology, selected by 40% of the sample, followed by environmental science (23%), conservation (22%), soil science (14%), entomology (12%), environmental studies (12%), geography (12%), agriculture (11%) and biology (11%), with numerous other disciplines also selected by smaller numbers of respondents (these percentages sum to >100 as respondents could choose more than one discipline) (Figure 2.2). The sample was split into two groups according to whether respondents identified ecology and/or conservation ($n=26$ ecology, $n=14$ conservation) as one of their disciplinary areas (we refer to these individuals as EcCon) or not ($n= 35$), in order to test the impact of academic discipline on risk perception and biosecurity practice.

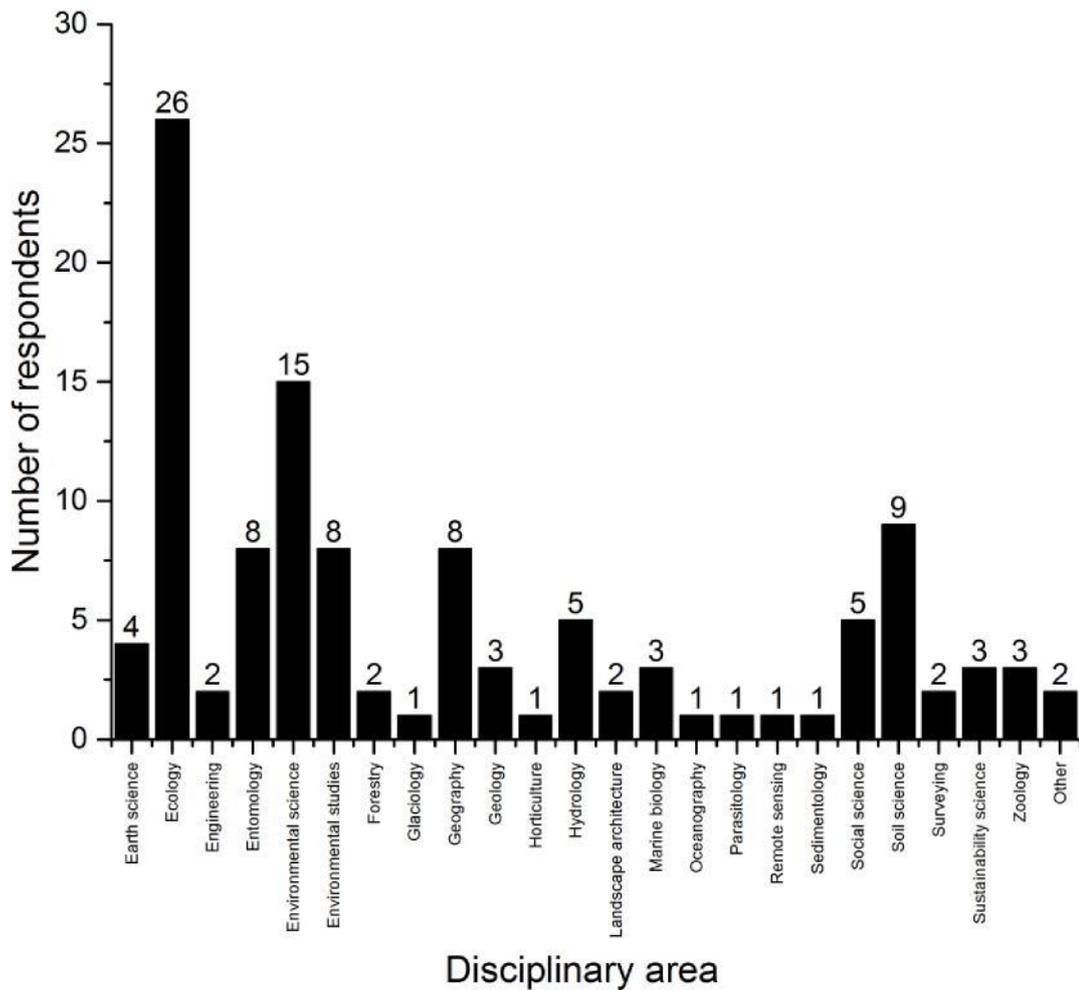


Figure 2.2 Disciplinary areas identified by researchers. Respondents were able to select up to four disciplinary areas with 40% of researchers selecting Ecology ($n = 26$) and 22% Conservation ($n=14$).

Nearly half of respondents ($n=31$) carried out fieldwork in woodland areas and 34% of respondents indicated that they carried out fieldwork in aquatic (combining marine and freshwater) environments (Figure 2.3). The most common activity among respondents was monitoring/surveying (69%) but nearly 60% of respondents also carried out sampling in the field (these percentages sum to >100 as respondents could choose more than one activity).

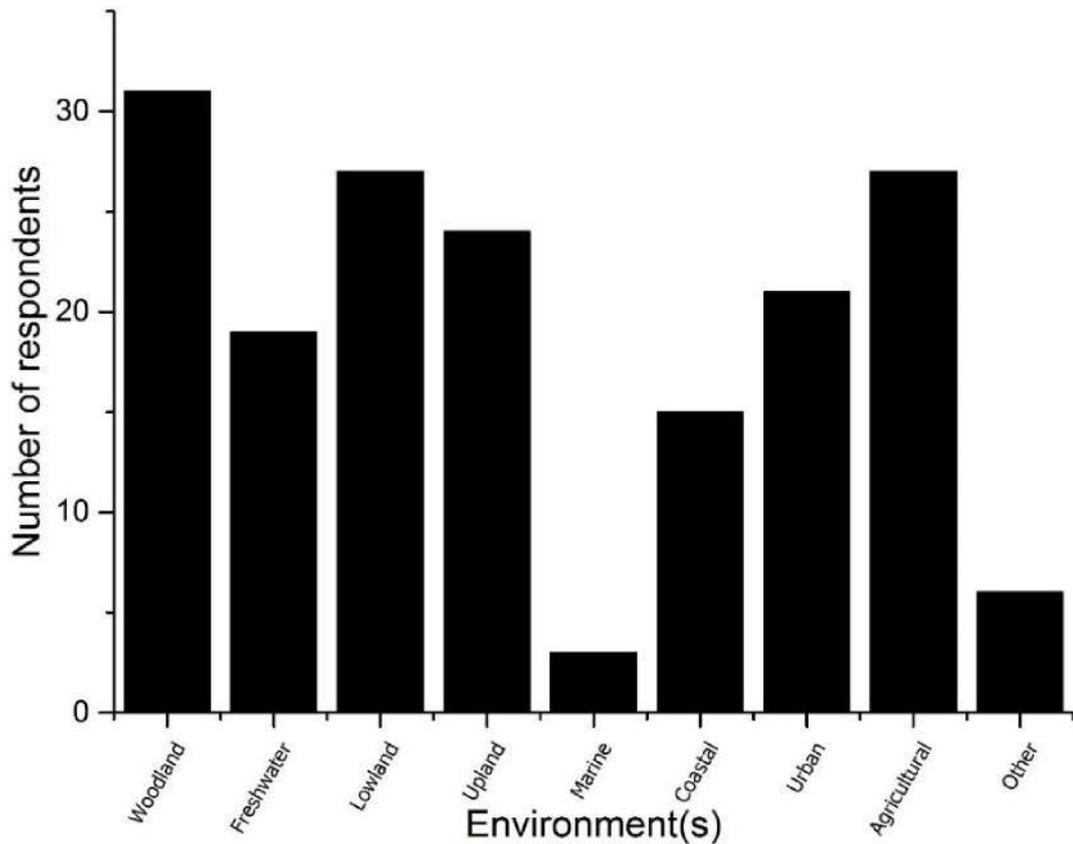


Figure 2.3 Environments in which respondents carried out field activities (choice of four; these numbers sum to >100 as respondents could choose up to four environments).

Woodland areas were identified as one of the most common environments for respondents to undertake fieldwork ($n=31$).

Individuals were asked whether they considered their field activities posed a risk in spreading IAS, individuals that answered yes were asked to measure their risk from low to high. Thirty-five percent of all respondents perceived that their field activities posed a risk of spreading IAS. For the respondents that considered their fieldwork to pose some risk in terms of spreading IAS, most respondents (78.2%) considered their activities to be medium to low risk on the Likert scale.

2.4.2 Impact of academic discipline, exposure to IAS and familiarity with biosecurity campaigns on risk perception and biosecurity practice.

There was no significant difference in perception of risk in the EcCon group (43% considered their field activities posed a risk of spreading IAS) compared to those from other non EcCon disciplines (29%) (Table 2.1). In contrast, researchers who reported exposure to IAS were significantly more likely to consider that their activities posed a risk of spreading IAS as were those who were familiar with biosecurity campaigns (Table 2.1).

For most respondents (55.4%), issues related to IAS never or rarely come up in relation to fieldwork. Respondents that had undertaken fieldwork in areas where IAS were suspected or known to be present (39%), were significantly more likely to perceive their field activities to entail risks of spreading IAS compared to those who had not undertaken fieldwork in areas where IAS were suspected or known to be present (Table 2.1). Forty percent of all respondents stated that they were familiar with biosecurity campaigns or guidance and of those that had encountered campaigns or guidance. Check, Clean, Dry and Be Plant Wise were mentioned, as were regulations on Japanese knotweed. Familiarity with biosecurity campaigns or guidance was significantly associated with risk perception, with 54% of those familiar with campaigns or guidance considering their field activities to constitute a risk in terms of spreading IAS, compared with only 23.1% of those who were not familiar with campaigns (Table 2.1). Risk perception was not significantly affected by the interactions between discipline, exposure to IAS, and familiarity with campaigns (two-way and three-way interactions, $p>0.05$).

A total of 28% of all respondents reported consciously employing biosecurity practices in the field. Of these individuals, the majority stated that they often avoided contact with IAS in the field (40%), often challenged the risky practices of others (38%), and sometimes found out whether IAS were present at their field sites (44%). No significant difference was found between respondents from the EcCon group and those from other, non-EcCon disciplines when reporting consciously employing biosecurity practices in the field (Table 2.1). On the other hand, actual cleaning scores were significantly better among those from EcCon compared to those from other disciplines (Table 2.1).

Respondents who reported exposure to IAS and had carried out activities where IAS were suspected or known to be present were significantly more likely to report consciously employing biosecurity measures, as were those who were familiar with biosecurity campaigns or guidance (Table 2.1). Of the 25 respondents (39%) that had carried out activities in an area where IAS were suspected or known to be present, most (60%) said that they did not change anything about how they carried out their field activities. Nonetheless, respondents that had undertaken fieldwork where IAS were suspected or known to be present were significantly more likely to report consciously employing biosecurity measures, with 52% doing so, compared with only 13% of the group that had not carried out fieldwork in the presence of IAS (Table 2.1). Those that did make changes to their activities because of encountering IAS in the field (40%), reported changing the order of sites visited, disinfecting equipment and following Check, Clean, Dry recommendations. Reported biosecurity was not significantly affected by the interactions between discipline, familiarity with campaigns, or exposure to IAS ($p>0.05$ for all two-way and three-way interactions).

However, the increased awareness and reporting of biosecurity by those who had been exposed to IAS did not appear to translate into actual biosecurity practices. There was no significant difference between mean scores of actual biosecurity practices of respondents that had carried out activities in areas where IAS were known or suspected and for those respondents who had not worked in these areas (Table 2.1).

In contrast, familiarity with biosecurity campaigns or guidance was significantly associated with both higher reported biosecurity and higher actual cleaning scores (Table 2.1). There was no significant effect of the interactions between discipline, exposure to IAS and familiarity with campaigns on cleaning scores (two-way and three-way interactions, $p > 0.05$).

Table 2.1 Risk perception, perceived biosecurity and actual biosecurity cleaning scores for respondents from different disciplines (EcCon versus other); respondents exposed/not exposed to IAS; and respondents who were/were not familiar with biosecurity campaigns or guidance.

	EcCon	Other	GLM
Risk perception (<i>considered to be a risk</i>)	43.3% (n=30)	28.6% (n=35)	$\chi^2 = 0.012$ d.f. =1 $p = 0.914$
Perceived biosecurity (<i>consciously employing biosecurity</i>)	33.3% (n=30)	22.9% (n=35)	$\chi^2 = 0.624$ d.f. = 1 $p = 0.429$
Actual biosecurity (<i>mean cleaning score</i>)	1.40 +/- SD 0.84 (n=30)	1.61 +/- 0.74 (n=35)	$F=5.188$, d.f. 1,61, $p = 0.026$
	Exposure to INNS	No exposure	GLM
Risk perception (<i>considered to be a risk</i>)	52% (n=25)	25% (n=40)	$\chi^2 = 4.637$ d.f. =1 $p = 0.031$
Perceived biosecurity (<i>consciously employing biosecurity</i>)	52% (n=25)	12.5% (n=40)	$\chi^2 = 12.271$ df. =1 $p = <0.001$
Actual biosecurity (<i>mean cleaning score</i>)	1.56 +/- SD 0.70 (n=25)	1.48 +/- SD 0.84 (n=40)	$F=0.063$, d.f. 1,62, $p = 0.803$
	Familiarity with campaigns	Not familiar	GLM
Risk perception (<i>considered to be a risk</i>)	53.84%(n=26)	23.1% (n=39)	$\chi^2 = 6.448$ df. =1 $p = 0.011$
Perceived biosecurity (<i>consciously employing biosecurity</i>)	46.2% (n=26)	15.4% (n=39)	$\chi^2 = 7.326$ df. =1 $p = 0.007$
Actual biosecurity (<i>mean cleaning score</i>)	1.77 +/- SD 0.84 (n=26)	1.34 +/- SD 0.71 (n=39)	$F=5.244$, d.f. 1,63, $p = 0.025$

2.4.3 Impact of field experience on risk perception and biosecurity practice

Respondents carrying out sampling in the field were significantly more likely to perceive that their field activities may constitute a risk of spreading IAS than those not carrying out sampling in the field (Table 2.2). Despite this higher reported perception that their activities pose a risk of spreading IAS, those undertaking sampling activities were not significantly more likely to report consciously employing biosecurity in the field. Nonetheless, respondents that took samples had higher mean cleaning scores than those that did not (Table 2.2).

In contrast there was no significant difference in risk perception, reported or actual biosecurity practices between those working in aquatic versus terrestrial environments (Table 2.2). There was no significant effect of the interaction between sampling and aquatic activity on risk perception ($p=0.608$), perceived biosecurity ($p=0.305$), or actual biosecurity ($p=0.788$).

Table 2.2 Risk perception, perceived biosecurity and actual biosecurity cleaning scores for respondents undertaking different activities in the field; sampling versus not taking samples; and aquatic versus terrestrial/other field work.

	Activity (sampling)	Other	GLM
Risk perception (<i>considered to be a risk</i>)	50% (n=38)	14.9% (n=27)	$\chi^2 = 9.142$ d.f. = 1 $p = 0.002$
Perceived biosecurity (<i>consciously employing biosecurity</i>)	28.9% (n=38)	25.9% (n=27)	$\chi^2 = 0.072$ d.f. =1 $p = 0.788$
Actual biosecurity (<i>mean cleaning score</i>)	1.70+/- SD 0.70 (n=38)	1.25+/- SD 0.84 (n= 27)	$F=5.362$, d.f. 1,63, $p = 0.024$
	Activity (Aquatic)	Other	
Risk perception (<i>considered to be a risk</i>)	54.5% (n=22)	25.6% (n=43)	$\chi^2 = 3.285$ d.f. =1 $p = 0.069$
Perceived biosecurity (<i>consciously employing biosecurity</i>)	36.4% (n=22)	23.3% (n=43)	$\chi^2 = 1.149$ d.f. =1 $p = 0.284$
Actual biosecurity (<i>mean cleaning score</i>)	1.54 +/- SD 0.70 (n=22)	1.50 +/- SD 0.84 (n= 43)	$F=0.091$, d.f. 1,62, $p = 0.764$

2.5 Discussion

This study provides the first test of key hypotheses, that knowledge and experience determine behaviour surrounding the implementation of biosecurity measures by a neglected group of stakeholders: field researchers. We measured the perceptions of risk an individual associated with their field activities and their reported and actual behaviours in relation to biosecurity of IAS in the environment. This work shows both the importance of experience in the field (e.g.

through sampling) and information campaigns/guidance as key components for behaviour change.

Surprisingly, respondents to the questionnaire with ecology and/or conservation disciplinary backgrounds were not more likely to consider that their activities posed a risk in introducing and/or spreading IAS despite the likelihood that they would know more about IAS issues. There was also no association between disciplinary background and likelihood of reporting employing biosecurity however there was an association between disciplinary background and conducting better biosecurity practices. This suggests that knowledge seemed to have no impact on an individual's risk perception and reported behaviour but was associated with actual behaviour.

Although field experience and exposure to IAS was positively associated with perceptions of risk and reported behaviour, researchers were not found to be undertaking better biosecurity practices. On the other hand, knowledge, as indicated by familiarity of campaigns seems to have a positive impact on an individual's perceived and actual behaviour. Whilst information campaigns are a relatively cheap method of communication and are somewhat successful in raising awareness of issues, they may not always lead to action (Collins et al. 2003; Lucas et al. 2008). Little is known about the success of campaigns targeting preventative behaviours in relation to IAS and the success of information campaigns in influencing behaviour is difficult to measure (Timlett and Williams 2008; Prinbeck et al. 2011). Our study reveals that awareness of campaigns and guidance led to both an increased perception of risk and to better biosecurity practice amongst researchers. These data are in accord with a study of recreational water users which found better biosecurity practice reported by canoeists who were aware of the Check Clean Dry campaign (Anderson et al. 2014).

Risk perceptions can be influenced by many variables including cultural background, personal values, attitudes and experience (Estévez et al. 2015). Drake et al. (2014) highlight the continued problem of human-mediated invasions, despite numerous outreach programs which aim to educate the public on the risks of introduction and spread, and encourage behaviour change among stakeholders. The broad range of incentives and motivations that determine behaviour need to be understood in order to devise and enforce targeted strategies (Perrings et al. 2002; Drake et al. 2014b). In this study, we found that perception was associated with previous exposure to IAS and with undertaking field sampling, which carry a higher risk of accidental transfer of IAS. Although individuals who undertake sampling activities were not more likely to report consciously employing biosecurity practices in the field, their biosecurity scores indicated that these individuals did in fact employ better biosecurity practices than

those that did not undertake sampling activities. This could be explained by the type of training they receive and knowledge that has been instilled in a “correct” way, which perhaps is aligned with better cleaning scores among people undertaking sampling activities. However, these individuals might not equate that with biosecurity and so may not report consciously employing better biosecurity practices. Surprisingly, individuals undertaking work in high risk, aquatic environments did not show higher risk perception, nor did they show higher reported or actual biosecurity practices in the field. Previous studies have found that whilst experience may have some impact on a person’s perception of risk, it is only partly related to an individual’s choice to make a conscious decision towards undertaking biosecurity practices (Perrings et al. 2002; Drake et al. 2014). Recent research on biosecurity with UK stakeholders has indicated that there are costs associated with implementing biosecurity, both monetary and in terms of time (Sutcliffe et al. 2017). It is likely that these costs might explain at least some of this disparity between recognition of risk and biosecurity action.

In our study, there is some mismatch between risk perception and perceived behaviour (individuals with aquatic field experience) and perceived and actual behaviour (individuals with previous exposure to IAS). In particular, individuals who had previous exposure to IAS considered themselves to be undertaking good biosecurity practices when in fact their actual cleaning did not reflect this. Other studies have identified that stakeholders can feel that they do not have enough clear advice on *how* to prevent the spread of IAS and that there is not enough evidence to suggest prevention methods are successful (Prinbeck et al. 2011; Sutcliffe et al. 2017), both of which will act as disincentives to changing behaviour. Infrastructure developments could potentially address the issue surrounding *how* to prevent the spread of IAS. For example, Anderson et al. (2014) suggest that cleaning stations are needed at hot spot locations to encourage biosecurity among anglers. Several studies have identified a gap between perceived/reported and actual behaviour in relation to pro-environmental actions, such as recycling (Corral-Verdugo 1997; O’Connor et al. 1999; Steg and Vlek 2009). Corral-Verdugo (1997) found a low correlation between self-reported and direct observations of recycling, while Woollam et al. (2003) found that many people exaggerated their recycling behaviour when asked because they recognised recycling as a ‘good’ thing and therefore wanted to give the ‘right’ answer. This exaggeration gap could provide an explanation for why individuals in our study reported consciously employing biosecurity in the field, even though this was not reflected in their actual practice. An alternative possible explanation for this gap between perceptions and practice might arise from the overestimation of current biosecurity activities. Efforts must be made to increase the willingness of stakeholders, including researchers, to implement biosecurity practices as provision of infrastructure alone will not

encourage stakeholders to manage, maintain and use it. What is needed is sustained education, communication, incentives and leading by example, alongside infrastructure provision (Sutcliffe et al. 2017). Without these, it will be difficult to create and maintain stakeholder buy-in for biosecurity. We must recognise that behaviours are determined by many factors, and all are necessary to trigger and sustain a change in behaviour.

2.6 Conclusion

There seems to be a gap between the risks people associate with their activities, and the measures they take to minimise this risk. Through application of quantitative research using an online questionnaire we were able to explore the relationship between risk perception and behaviour in relation to biosecurity among a sample of researchers within the UK. Our results suggest that awareness raising campaigns have been successful in targeting behaviour change, however there is a large proportion of field researchers who recognise their activities pose a risk to the introduction and/or spread of IAS but do not employ behaviours to mitigate this risk. As a result, this group requires a specific intervention approach to target their actions. We propose that awareness raising campaigns be coupled with better biosecurity guidance and training.

Training and guidance should be clear and concise in order to explain and demonstrate what constitutes good biosecurity. For example, using real life examples of situations where people may encounter IAS and the measures they should put in place could help to address the gap between perceiving risks and actually employing biosecurity practices. Field training and demonstrating biosecurity in the field (in high risk environments including aquatic) could also target individuals that believe they are undertaking biosecurity practices but in fact are not employing 'good' cleaning practices. Raising awareness of the potential long-term consequences of undertaking poor biosecurity might also make stakeholders more aware of how significant the impacts of their activities can be. Training on *how* to do biosecurity should support campaigns that aim to raise awareness and advise people *what* to do. e-Learning courses have been used as a tool to reinforce and improve standards for good biosecurity in the field. Whilst these courses should not be used as a stand-alone method, taking advantage of new technology can help to improve the learning process in addition to information campaigns (Seixas et al. 2015). The Great Britain Non-Native Species Secretariat also offers free biosecurity e-Learning courses on how to plan and practice Check Clean Dry in the field for anyone who uses the environment for work or leisure. The University of Leeds and Cefas have recently developed a free open access e-Learning module (<https://openeducation.blackboard.com/mooc->

[catalog/courseDetails/view?course_id= 1189 1](#)) which is aimed at field researchers. By targeting undergraduates, postgraduates and field staff, this e-Learning training aims to raise awareness and train individuals undertaking fieldwork in better biosecurity practices. Increasing education and awareness among these individuals will create a legacy, and train the next generation of academics, environmental managers and conservationists in better biosecurity. Individuals conducting research in the field still pose a risk to the introduction and/or spread of IAS into new environments, but with better communication on the *what* and training in the *how* the introduction and spread of IAS can be reduced.

2.7 References

Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD. 2015. Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biol Invasions* 17:2287–2297. doi: 10.1007/s10530-015-0875-6

Anderson LG, White PC, Stebbing PD, et al. 2014. Biosecurity and vector behaviour: evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLoS One* 9:1–10. doi: 10.1371/journal.pone.0092788

Ballantyne R, Packer J. 2005. Promoting environmentally sustainable attitudes and behaviour through free choice learning experiences: what is the state of the game? *Environ Educ Res* 11:281–295. doi: 10.1080/13504620500081145

Collins J, Thomas G, Willis R, Wilsdon J. 2003. Carrots, sticks and sermons: influencing public behaviour for environmental goals. Green Alliance, London

Corral-Verdugo V. 1997. Dual “realities” of conservation behaviour: Self-reports vs observations of re-use and recycling behaviour. *J Environ Psychol* 17:135–145. doi: 10.1006/jevp.1997.0048

Crawley M. 2007. *The R book*. Wiley, Chichester

Defra. 2015. *The Great Britain Invasive Non-native Species Strategy*. <http://www.nonnativespecies.org/index.cfm?sectionid=55>. Accessed 13 Feb 2017

Delabbio JL, Johnson GR, Murphy BR, et al. 2005. Fish disease and biosecurity: Attitudes, beliefs, and perceptions of managers and owners of commercial finfish recirculating facilities in the United States and Canada. *J Aquat Anim Health* 17:153–159. doi: 10.1577/H04-005.1

Drake AR, Mercader R, Dobson T, Mandrak NE. 2014. Can we predict risky human behaviour involving invasive species? A case study of the release of fishes to the wild. *Biol Invasions* 17:309–326. doi: 10.1007/s10530-014-0729-7

Dudgeon D, Arthington AH, Gessner MO, et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol Rev Camb Philos Soc* 81:163–82. doi: 10.1017/S1464793105006950

Dunn AM, Hatcher MJ. 2015. Parasites and biological invasions: Parallels, interactions, and control. *Trends Parasitol* 31:189–199. doi: 10.1016/j.pt.2014.12.003

Estévez RA, Anderson CB, Pizarro JC, Burgman MA. 2015. Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conserv Biol* 29:19–30. doi: 10.1111/cobi.12359

García-Llorente M, Martín-López B, Nunes PA, et al. 2011. Analysing the Social Factors That Influence Willingness to Pay for Invasive Alien Species Management Under Two Different Strategies: Eradication and Prevention. *Environ Manage* 48:418–435. doi: 10.1007/s00267-011-9646-z

Lorenzoni I, Nicholson-Cole S, Whitmarsh L. 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. *Glob Environ Chang* 17:445–459. doi: 10.1016/j.gloenvcha.2007.01.004

Lucas K, Brooks M, Darnton A, Jones JE. 2008. Promoting pro-environmental behaviour : existing evidence and policy implications. *Environ Sci Policy* 11:456–466. doi: 10.1016/j.envsci.2008.03.001

Miller RL, Brewer JD. 2003. *The A-Z of Social Research: A Dictionary of Key Social Science Research Concepts*. SAGE Publications, London

O'Connor RE, Bard RJ, Fisher A, et al. 1999. Risk perceptions, general environmental beliefs, and willingness to address climate change. *Risk Anal* 19:461–471. doi: 10.1111/j.1539-6924.1999.tb00421.x

Perrings C, Williamson M, Barbier EB, et al. 2002. Biological invasion risks and the public good: An economic perspective. *Conserv Ecol* 6:1–7

Prinbeck G, Lach D, Chan S. 2011. Exploring stakeholders' attitudes and beliefs regarding behaviours that prevent the spread of invasive species. *Environ Educ Res* 17:341–352. doi: 10.1080/13504622.2010.542451

R Core Team. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Seixas S, Saravanan S, Gonçalves S. 2015. Innovation and educational changes: two e-Learning cases in aquaculture. *Aquac Int* 23:843–859. doi: 10.1007/s10499-014-9850-y

Shackleton CM, Shackleton RT. 2016. Knowledge, perceptions and willingness to control designated invasive tree species in urban household gardens in South Africa. *Biol Invasions*. doi: 10.1007/s10530-016-1104-7

Steg L, Vlek C. 2009. Encouraging pro-environmental behaviour: An integrative review and research agenda. *J Environ Psychol* 29:309–317. doi: 10.1016/j.jenvp.2008.10.004

Sutcliffe C, Quinn CH, Shannon C, et al. 2017. Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biol Invasions*. doi: 10.1007/s10530-017-1541-y

Timlett RE, Williams ID. 2008. Public participation and recycling performance in England: A comparison of tools for behaviour change. *Resour Conserv Recycl* 52:622–634. doi: 10.1016/j.resconrec.2007.08.003

Woollam T, Emery A, Griffiths A, Williams KA. 2003. A comparison of intended and claimed recycling behaviour to actual in a new kerbside scheme. *CIWM Sci Tech Rev* December 2003: 2-9

Chapter 3: Coherence of marine invasive alien species biosecurity legislation: a study of England and Wales

3.1 Abstract

The marine environment is particularly at risk from intentional and unintentional introduction and spread of IAS. Once introduced and established, IAS are difficult to control or eradicate, particularly in the marine environment. This highlights the importance of preventing introduction and spread of IAS from occurring in the marine environment; biosecurity is therefore an important tool to slow the spread of IAS. International, regional and national policy instruments have been implemented to address the impact of IAS on the environment, economy and society. Ensuring these policy instruments are coherent at an international and national level is key to the success of managing the existing and future impacts of IAS in the marine environment and managing the key pathways such as shipping, recreational boating and aquaculture. We explore the coherence of marine biosecurity policy (as an intervention tool) for IAS at an international and national scale. There was positive interaction between the two conventions, and between the conventions and European and national legislation. Unlike other European legislation, the EU IAS Regulation has not yet been transposed into national legislation however the regulation can be directly applied without being transposed. Both the Bern Convention and Convention on Biological Diversity were consistent with European and national legislation that had been created in response. There was a lack of vertical and horizontal interaction as evidenced by the Ballast Water Management Convention which had not yet been transposed into European or national legislation. There has also been a recent shift to voluntary instruments to address biosecurity of IAS in the marine environment which aim to complement and reinforce legislation. These results suggest that in order to successfully manage IAS in the marine environment, implementation measures such as policy instruments (both voluntary and legislative) should be coherent as any failure in the chain could potentially weaken the overall effort to establish and maintain biosecurity and achieve behaviour change.

3.2 Introduction

Marine non-native species are organisms that have been moved into new areas outside of their natural range as a result of human activities (e.g. shipping, recreational boating and aquaculture) (Katsanevakis et al. 2013). Whilst most non-native species do not cause problems, a minority have the potential to become invasive and have negative environmental, social and economic impacts (Ricciardi and MacIsaac 2010; IMO 2011; Sambrook et al. 2014);

here after referred to as invasive alien species (IAS). The primary cost of IAS to the United States, United Kingdom, Australia, South Africa, India and Brazil combined has been estimated at over \$314 billion per annum (Pimentel et al. 2005), in the European Union (EU), IAS are estimated to cost approximately \$14 billion a year (£11 billion) (Kettunen et al. 2009), and in Great Britain £1.7 billion per year (\$2.2 billion) (Williams et al. 2010). According to the International Maritime Organization (IMO) the introduction of IAS to new environments has been identified as one of the four greatest threats to the world's oceans (IMO 2011). For example *Didemnum vexillum* (carpet sea squirt) can form large colonies and smother surfaces on which it grows, including fishing equipment, boats, and native reef habitats (Williams and Grosholz 2008; Sambrook et al. 2014).

In the marine environment, IAS can spread through a variety of human mediated pathways (Hulme et al. 2016). Human-mediated pathways are those that are created or enhanced by human activity, which can be intentional or unintentional (Nunes et al. 2015). Aquaculture is a good example to illustrate both intentional and unintentional pathways for IAS. Globally, there has been an increasing reliance on aquaculture to provide food security and economic development, this has led to an increase in the intentional introduction of IAS for cultivation (Campbell and Hewitt 2013; Grosholz et al. 2015). For example, *Ruditapes philippinarum* (Manila clam) was intentionally introduced in several regions worldwide (e.g. North America, mainland Europe, UK) because of its considerable commercial value (Moura et al. 2017). Once introduced and established, IAS are difficult to control or eradicate, particularly in the marine environment (Katsanevakis et al. 2013; Tidbury et al. 2016). This highlights the importance of preventing introduction and spread of IAS from occurring in the marine environment.

Preventing the introduction and spread of IAS by pathway management is therefore the first and most cost effective control measure and can prevent huge economic costs in the future. However, preventing unintentional introductions and spread is extremely challenging, in part because it relies on the cooperation of stakeholders as well as developing legislation for each pathway, identifying the different sectors involved, and reaching binding agreements (Hulme et al. 2008; Williams and Grosholz 2008). Prevention measures, such as biosecurity, are implemented through policies and legislative drivers that aim to mitigate the impacts of IAS in the marine environment. Policy is a collection of different instruments used by governments to pursue a desired outcome; these instruments attempt to form a coherent strategy to achieve the outcome through conventions, regulations, directives, and legislation (Carter 2007).

We refer to policy to include conventions, legislation and regulation and directives.

Conventions are agreements between countries which help to promote cooperation and the

development of law on common issues of interest. Legislation (or law), is a legally binding agreement that attempt to achieve international goals at a regional, national or local level. Regulations are a binding legislative act which must be adopted and uses penalties and incentives in an attempt to influence the behaviour of stakeholders. Directives are also a legislative act that set out a goal which needs to be achieved, however each individual country (e.g. EU states) must devise their own laws on to reach these goals. A combination of the above policies can be used to achieve the goals of conventions (Lucas et al. 2008). When used together, policy instruments may produce different results than anticipated, including synergies or counter-effects (Santos et al. 2010). Understanding the coherence of policies, their consistency and how they interact is considered to be one of the most important issues in environmental governance and can help to identify synergies and conflicts between existing policy and how they influence each other's effectiveness (Carter 2007). The degree of consistency between policies, regarding contradictions or conflicts, is also important to consider (Nilsson et al. 2012; Strambo et al. 2015). Consistency can improve effectiveness of implementation as having inconsistent and incoherent policies can send confusing or conflicting messages to stakeholders (Howlett and Rayner 2007; Owens and Driffill 2008). Incoherent and conflicting policies will ultimately limit the effectiveness of policy on the ground (Schillo et al. 2017).

Policy analysis can help assess how global policy decisions are introduced into national systems, and can provide insight into the relationship between policies for managing the pathways of marine non-native species (May et al. 2006; Nilsson et al. 2012; Kivimaa and Virkamäki 2014). For example, in the field of climate policy, Strambo et al (2015) highlights many inconsistencies (as well as synergies) between climate change mitigation and energy security policies in the EU. Similarly, Höhne et al (2017) argue that there are inconsistencies between current national actions to achieve the long-term goals of the Paris Agreement and discuss factors that could strengthen national action to reduce emissions in order to be more consistent with the agreed global long-term goals. Having a coherent policy framework at an international and national level is key to the success of managing the existing and future impacts of IAS in the marine environment. Policy instruments set standards of what is acceptable behaviour for target groups (Carter 2007); therefore policy instruments work at the group level to influence norms and a persons' intention to behave (Ajzen 1991). Whilst there is a sizeable literature on coherence in other related topic areas (mainly climate policy), currently no analysis has been applied to IAS in the marine environment.

The overarching aim of this study is to explore the coherence of marine IAS policy at an international and national scale. The objectives of the work are: a) investigate the consistency

and, b) the interaction of policies at international, regional and national levels and c) identify gaps and limitations in existing marine non-native species policy and their implications for implementation in England and Wales. Global policy was identified at the international level, regional policy at the European scale, whilst national policy was for England and Wales. The study excluded national policies from Northern Ireland and Scotland due to different political systems and policies dealing with non-native species at the national level.

3.3 Research design and methodology

3.3.1 Data collection and analysis

Policy documents were purposefully selected using a top down approach, as this approach is better suited to exploring the coherence between the written content of policies formulated internationally. This approach allows the researcher to track the consistency of policy down through governance levels, and study the interaction of these policies (Urwin and Jordan 2008).

Three international conventions were identified by literature review as the most relevant international agreements for this study: the Convention on Biological Diversity (CBD) (1992), the Bern Convention (1982), and the Ballast Water Management (BWM) Convention (2017). It is important to note that whilst the Bern Convention is considered an 'international Convention' it only applies to European States. The main websites for each of the three conventions were searched for online (e.g. the CBD on www.cbd.int/). These websites were then searched for relevant European and national (England and Wales) policy which aimed to implement the goals of the conventions. The policies that were identified from the convention websites included legislation, directives and regulations. Websites for European and national policy included European law ([Europa.eu](http://europa.eu)) and the National Archive ([Legislation.gov](http://legislation.gov.uk)). Additional policy that was not directly related to, or resulted from any of the three conventions were identified through a search of IAS policy, using the Great Britain Non-Native Species (GBNNS) Secretariat webpage on 'Legislation and Regulation' relevant for Great Britain (<http://www.nonnativespecies.org//index.cfm?pageid=67>). These included regulations on the use of IAS in aquaculture. It should be noted that the selected policies were not intended to be an exhaustive list of all of the Government's policy efforts for England and Wales, rather they were chosen to illustrate the implementation of international agreements at a European and national scale.

3.3.2 Policy consistency

The 13 international and national policy documents identified were analysed using iterative qualitative content analysis which is widely used in policy analysis (Schreier 2012; Kalaba et al. 2014). This is an approach where text is analysed and coded.

Vertical policy consistency (compatibility of policy aims/actions top down without conflict) was determined by analysing policy documents using the following pre-determined categories: aims of policy, relevance to conventions, primary interest and terminology. Each category included codes, and search terms that were used to search each policy document (Table 3.1). Samples of text for each category and code were put into a combined matrix (Appendix D).

Table 3.1. Pre-determined categories, codes and code description for content analysis

Category	Code	Search terms
Aims of policy documents	Aim	Aim, goal, objectives, target
Relevance to conventions	Bern Convention CBD BWM Convention	Convention on the Conservation of European Wildlife and Natural Habitats/ Bern Convention Convention on Biological Diversity/ CBD Ballast Water Management Convention/BWM Convention
Primary interest	Environmental	Nature conservation, marine conservation, biodiversity, sustainability, environment, plants, a flora
	Economic	Economic, economy, production, cost, finance, income, output
	Social	Sustainability, development, health, society, welfare, economy
	Trade	Trade, economy, transport, deal, agreement, goods, services, business, sell
	Travel	Transport, location, air, land, sea, shipping, vehicle
Terminology	Prevention	Prevention Biosecurity
	Invasive	Non-native, invasive non-native, alien, non-indigenous, introduced

An iterative process was used to search all the policy documents for their general or IAS related aim(s). The term 'aim' was not always used consistently in policy documents and therefore search terms included 'aim', 'goal', 'objective' and 'target' (Table 3.1). All terms were combined and from here forward are referred to as 'aim'. The identified policy aims were then used to evaluate the interaction of policies.

European and national legislation and policy documents were also searched for reference to either of the three conventions to track their implementation.

Each policy document was coded as either environmental, economic, social, travel or trade according to the code description and search terms, and more than one code could be used to identify the broad primary interest. The primary interest of each document was again used to evaluate interactions.

Because of the debate around the type of terminology used in IAS science and how the choice of terminology or lack of common terminology can heavily determine the implementation of policy objectives (Larson 2005), each policy document was coded to determine the type of terminology used, and highlighted where and if the terminology was defined. The terminology from the Bern Convention, CBD and BWM Convention were tracked down through European and national policy to determine whether the terminology and definitions were linear from a top down perspective.

3.3.3 Policy interaction

Both vertical (e.g. international and European) and horizontal (e.g. European and European) interactions between policy aims (identified in the previous section), were assessed to determine how the aims of one policy impacted the effectiveness of achieving the aims in another policy. The interaction was assessed as either positive, negative or neutral. Positive interaction was determined when one policy aim supported the aims of another, for example if two policies shared the same aims or if one policy aim enhanced that of another. Negative interaction was determined when one policy aim had the potential to, or evidently conflicted (or prevented) that of another aim being achieved. For example, if one policy document allowed a certain activity whilst another policy document prohibited it. A neutral interaction was identified when neither policy aim had any relevance to that of another, for example it neither enhanced nor discouraged a policy aim.

3.4 Results

3.4.1 Consistency

3.4.1.1 General aim(s) of policy documents and relevance to IAS

The general aims of the international conventions (the Bern Convention, the CBD and the BWM Convention) as well as European and national legislation, and the relevance to IAS can be found in Table 3.2. All three conventions state that IAS are damaging to the environment,

economy and society and need to be controlled and managed, therefore there are no conflicts between the aims of the conventions. The Bern Convention covers the whole of Europe and is a binding legal instrument that sets out aims and objectives to conserve European wildlife and habitats. According to the Bern Convention (Article 11(2b)) all parties should 'strictly control the introduction of non-native species'. On a global scale, the CBD is an international legally-binding treaty (ratified agreement between states) that aims to develop regional and national strategies for the conservation and sustainable use of biological diversity. The CBD uses a three stage approach of prevention, early detection and rapid response and long-term management to address the issue of IAS on global biodiversity. The CBD identifies IAS as one of the biggest threats to biodiversity and therefore recognises that there is an urgent need to address the impact of IAS. The BWM Convention treaty was proposed by the IMO which is the United Nations agency for shipping. The convention is a pathway specific convention that is directed at specific activities within the marine environment (i.e ballast water and sediment). So far the BWM Convention has been ratified by 59 states including the UK in 2017; however the convention is yet to be transposed into European or national legislation .

Top down (vertically), the aims of the Bern Convention and the CBD are consistent with European regulations. For example, the EU IAS regulation requires pathway action plans to be implemented and are therefore consistent with the aims of the BWM.

Table 3.2 General aims, relevance to IAS and primary interest of international conventions and European and national legislation

Scale	Document	General aim(s)	Relevance to IAS	Primary interest(s)
International convention	The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982	The principle aims of the Convention are to ensure conservation and protection of wild plant and animal species and their natural habitats, to increase cooperation between contracting parties, and to regulate the exploitation of those species listed (including migratory species).	The Bern Convention is a binding international legal instrument in the field of nature conservation. The Convention recognises that IAS pose a significant threat to the aims of conserving wild flora and fauna and their natural habitats within Europe and therefore the introduction of IAS must be controlled.	Environmental
	The Convention on Biological Diversity (CBD) 1992	As the first global treaty to provide a legal framework for biodiversity conservation, the Convention established three principle goals. (1) the conservation of biological diversity, (2) the sustainable use of its components, (3) the fair and equitable sharing of the benefits arising from the use of	Article 8(h) of the CBD states that Parties should "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".	Environmental

		genetic resources.		
	Ballast Water Management Convention (BWM) 2017	The principle aim of the BWM Convention is to prevent the spread of harmful aquatic organisms, by establishing standards and procedures for the management and control of ships' ballast water and sediments.	Introduces a global framework to control the transfer of potentially IAS in ships' ballast water.	Environmental Economic Travel Trade
European legislation	Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	The principle aim of the Habitats Directive is to promote the maintenance of biodiversity by requiring Member States to take measures to maintain or restore natural habitats and wild species listed on the Annexes to the Directive at a favourable conservation status, introducing robust protection for those habitats and species of European importance.	Article 22 of the Directive requires Member States to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction."	Environmental
	Water Framework Directive (WFD) 2000/60/EC	The purpose of the Directive is to establish a framework for the protection of inland surface waters (rivers and	Aim to achieve or maintain a good ecological status for European inland, transitional and coastal waters and	Environmental

		lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status'.	prevent their further deterioration. Non-native species are one of the significant pressures that could result in a water body failing to meet environmental objectives (such as failing to achieve good ecological status).	
	Marine Strategy Framework Directive (MSFD) 2008/56/EC	The MSFD outlines a legislative framework for an ecosystem-based approach to the management of human activities which supports the sustainable use of marine goods and services. The overarching goal of the Directive is to achieve 'Good Environmental Status' (GES) by 2020 across Europe's marine environment.	IAS are considered to prevent good environmental status being achieved. Descriptor 2 states that "Non-indigenous species introduced by human activities are at levels that not adversely alter the ecosystem".	Environmental Social Economic
	Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture	The principle aim is to ensure there is adequate protection of aquatic habitats.	Establishes a dedicated framework to assess and minimise the possible impact of alien and locally absent species used in aquaculture in the aquatic environment.	Environmental Economic

	Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS	The principle aim is to set three distinct types of measures which follow an internationally agreed hierarchical approach to combatting IAS: Prevention, Early detection and rapid eradication and Management.	This imposes restrictions on a list of species known as 'species of Union concern', published in Commission. These are species whose potential adverse effects across the European Union are such that concerted action across Europe is required. The list then managed with Member States using risk assessments and scientific evidence.	Environmental Social Economic
National legislation	The Wildlife and Countryside Act 1981	The Wildlife and Countryside Act 1981 is the primary legislation which protects animals, plants and habitats in the UK.	Section 14(1) of the Act makes it illegal to release or allow to escape into the wild any animal which is not ordinarily resident in Great Britain and is not a regular visitor to Great Britain in a wild state or is listed in Schedule 9 to the Act.	Environmental
	The Conservation of Offshore Marine Habitats and Species Regulations 2017	The Conservation of Habitats and Species Regulations 2017 form the legal basis for the implementation of the Habitats and Birds Directives	The regulation makes it an offence to deliberately introduce any live non-native animal or plant which would give rise to a risk of prejudice to natural habitats	Environmental

		in terrestrial areas and territorial waters out to 12nm in England and Wales (including the inshore marine area) and to a limited extent in Scotland and Northern Ireland.	within their natural range or a risk of prejudice to wild native flora or fauna.	
	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017	This Regulation transposes the Water Framework Directive into national law in the UK. The Regulations outline the duties of regulators in relation to environmental permitting, abstraction and impoundment of water in order to achieve “good status” (or good ecological potential for artificial or heavily modified water bodies).	Non-native species are one of the significant pressures that could result in a water body failing to meet environmental objectives (such as failing to achieve good ecological status).	Environmental
	Marine Strategy Regulations 2010	This statutory instrument transposes the requirements of the MSFD into UK legislation and requires the UK to take necessary measures to achieve or maintain a good environmental status in the	Achievement of GES will be assessed against eleven descriptors which include descriptor 2: Non-indigenous species introduced by human activities are at levels that do	Environmental

		marine environment by 2020.	not adversely alter the ecosystems	
	The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011	This Regulation implements Council Regulation (EC) 708/2007. It makes provision with respect to permits issued by the competent authority under the Regulation, notifying movement of Annex IV species or locally absent species, environmental risk assessments, contingency plans and monitoring.	Establishes a dedicated framework to assess and minimise the possible impact of alien and locally absent species used in aquaculture in the aquatic environment. A risk assessment is needed to import a new species into the UK or to relocate.	Environmental Economic

3.4.1.2 Relevant European and national legislation

Both the CBD and the Bern Convention have been transposed into European and national legislation through various policies (Figure 3.1, Table 3.3).

Regionally the Council Regulation concerning the use of alien and locally absent species in aquaculture, the EU Regulation on IAS and the MSFD were created to implement the goals agreed in the CBD. Nationally, the Marine Strategy Regulations and the Alien and Locally Absent Species in Aquaculture Regulations both transpose the requirements of the European legislation, whilst the EU Regulation on IAS is yet to be transposed on a national scale in England and Wales.

As a signatory, the European Union meets the obligations of the Bern Convention through the Habitats Directive, the WFD and the MSFD. The obligations of the Bern Convention have been transferred from European legislation to national (England and Wales) legislation by means of the Wildlife and Countryside Act, the Conservation of Offshore Marine Habitats and Species Regulations.

The BWM Convention is relatively new and in early stages of implementation, therefore there are currently no regional or national legal instruments that implement the aims of the convention. However, voluntary ballast water guidelines have recently been replaced by mandatory management requirements.

Table 3.3 Terminology used in international conventions, regional and national legislation and relevant international agreements for European and National legislation

Scale	Document	Relevant international agreements	Terminology used in relation to IAS and biosecurity
International agreements	The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982		Non-native species
	The Convention on Biological Diversity (CBD) 1992		Prevent Alien species
	Ballast Water Management Convention (BWM) 2017		Invasive aquatic species
European legislation	Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	Bern Convention	Non-native species
	Water Framework Directive (WFD) 2000/60/EC	Bern Convention	(Pollution) prevention and control
	Marine Strategy Framework Directive (MSFD) 2008/56/EC	Bern Convention CBD	Non-indigenous species
	Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture	CBD	Alien species Locally absent species Prevent the introduction

	Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS	CBD	Alien species Invasive alien species Invasive alien species of Union concern Invasive alien species of Member State concern Prevention
National legislation	The Wildlife and Countryside Act 1981	Bern Convention	Preventing serious damage (to livestock) Invasive non-native species of animal or plant
	The Conservation of Offshore Marine Habitats and Species Regulations 2017	Bern Convention	Prevention (of deterioration of habitats and disturbance of species and the spread of disease) Non-native species
	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017	Bern Convention	Prevent (deterioration of the status of each body of surface water)
	Marine Strategy Regulations 2010	CBD	Prevent (inputs into the marine environment)
	The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011	CBD	Alien Locally absent species

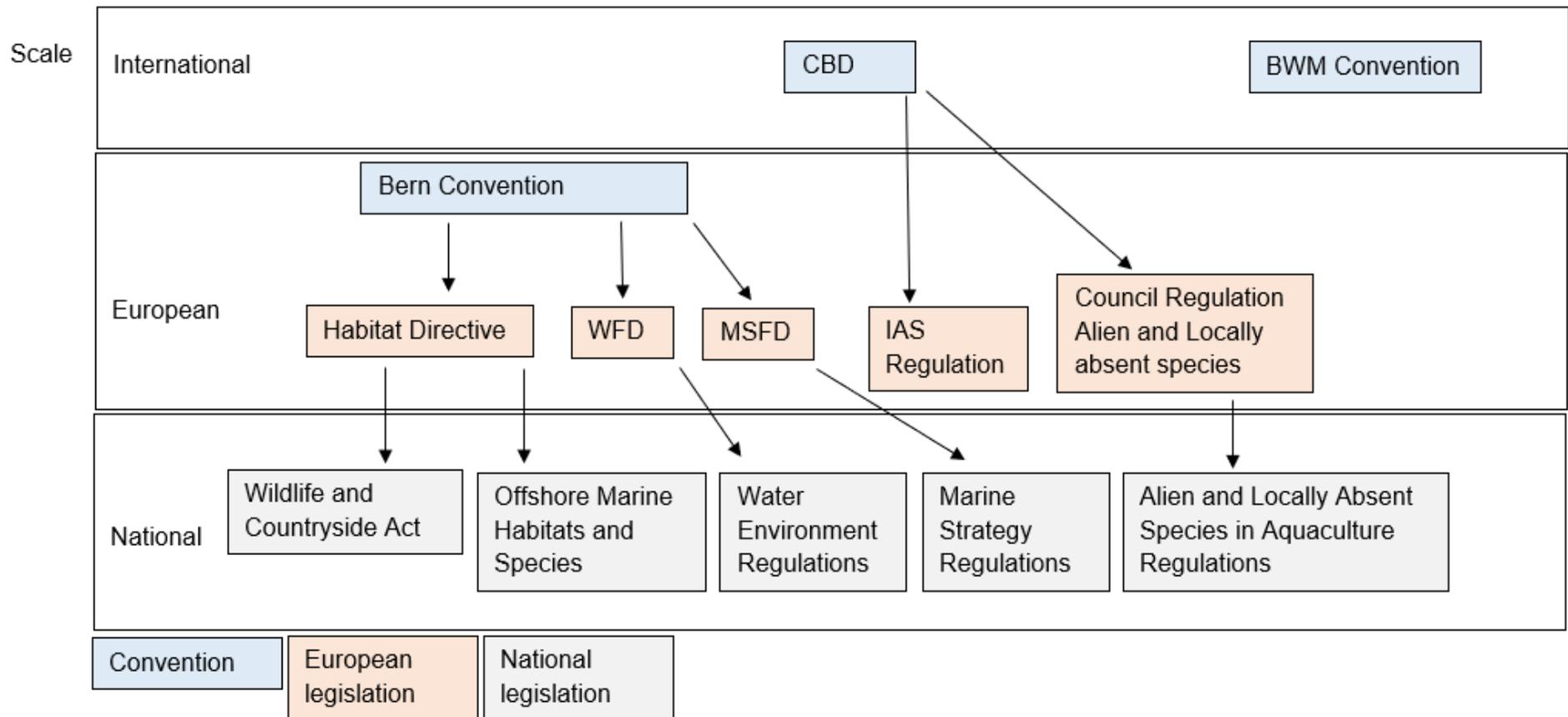


Figure 3.1. International agreements and relevant European and national law. Arrows indicate related national and European legislation to illustrate flow.

4.1.3.3 Primary interest

All three conventions were concerned with environmental protection and achieving conservation and sustainability targets (Table 3.2). Within European policy the Habitat Directive, WFD and MSFD were all conservation focussed and aimed to protect biodiversity within the marine environment. Council Regulation concerning the use of alien and locally absent species in aquaculture and the IAS Regulation were also environmentally focussed, specifically on addressing the impacts of IAS.

Not all conventions were solely focused on environmental issues. For example, the BWM Convention also included travel and trade and economic interests as the Convention targets the shipping industry in relation to IAS. Also, both Council Regulation concerning the use of alien and locally absent species in aquaculture and the national counterpart were also concerned with social and economic interests as the industry is concerned with risks to businesses.

3.4.1.4 Terminology

The term ‘non-native species’ was used by the Bern Convention. The term ‘non-native species’ was tracked down to the European level within the Habitat Directive and on a national level in the Wildlife and Countryside Act and the Conservation of Offshore Marine Habitats and Species Regulations (Table 3.3; Figure 3.2). As a signatory, the EU meets the obligations of the Bern convention through these policies. However, there were other European (WFD, MSFD) and national (the Water Environment Regulations, the Marine Strategy Regulations) laws that did not use the Bern Convention terminology. The MSFD used the term ‘non-indigenous species’ which is not found in any other policies. No term used synonymously with ‘non-native’ was used within the Water Environment Regulations nor the Marine Strategy Regulations.

The Bern Convention itself did not refer to prevention or biosecurity. On both a European level and national level, policies referenced prevention but this was in the context of water pollution and deterioration of the water body or ‘crops, livestock, forests, fisheries and water and other types of property’ (Habitat Directive).

The CBD used the term ‘alien species’. Both European (Council Regulation concerning the use of alien and locally absent species in aquaculture, IAS Regulation) and national (Alien and Locally Absent Species in Aquaculture Regulations) related policy used the same terminology. Prevention is one of three guiding principles recommended by the CBD in dealing with IAS. The term prevention was also used at a European level by the IAS Regulation and Regulation

concerning the use of alien and locally absent species in aquaculture. The term prevention is not yet in any existing national legislation related to the CBD, excluding the Marine Strategy Regulations that are related to both the CBD and Bern Convention and refer to the prevention of inputs into the marine environment.

The BWM Convention used the term 'invasive aquatic species' and referred to 'prevention' with a goal to 'reduce, or eliminate the transfer of Harmful Aquatic Organisms and Pathogens through ships' Ballast Water and Sediments' (BWM Convention, 2017). There is currently no existing national legislation that implement the BWM Convention and therefore the terminology could not be tracked.

3.4.2 Interaction

3.4.2.1 Vertical interaction

There was evidence of positive vertical interaction between the aims of the Conventions, and the aims of European and national legislation (Appendix E). There was evidence that both the Bern Convention and CBD had been transposed into European and national legislation, and these highlight the impact of IAS on the environment, economy and in society. For example, the EU IAS Regulation used the same three-stage approach to address IAS as the CBD. Similarly, the Regulation concerning the use of alien and locally absent species in aquaculture established a framework using the same approach as the CBD, similarly to the EU IAS Regulation. Whilst there was no negative interaction between the BWM Convention and national legislation, there were areas of neutral interaction. For example, there was no negative nor positive interaction between the BWM Convention and the Habitat Directive, the Regulation concerning the use of alien and locally absent species in aquaculture (European), the Wildlife and Countryside Act and the Alien and Locally Absent Species in Aquaculture Regulations (national). This was because the aims of the BWM convention neither supported nor conflicted with the aims of these regulations as they focused on different habitats and activities.

Whilst most interactions from European to national legislation were positive, there was evidence of some negative vertical interaction between Council Regulation concerning use of alien and locally absent species in aquaculture and the Wildlife and Countryside Act. The Wildlife and Countryside Act aims to protect animals, plants and habitats in the UK and makes it illegal to release or allow escape into the wild any animal which is not ordinarily resident in England and Wales and is not a regular visitor in a wild state or is listed in Schedule 9 to the Act. This conflicts with the Regulation concerning use of alien and locally absent species in

aquaculture which supports the use of IAS for farming and it carries a high risk of accidental escape.

Terminology was linear under each Convention with no cross over between the Bern Convention and CBD related policy documents (i.e Bern Convention documents related to non-native species whilst the CBD documents referred to the term 'alien'). However, both used the term 'invasive' to describe alien/non-native species with a negative environmental, social or economic impact.

3.4.2.2 Horizontal interaction

There was evidence of positive horizontal interactions between policies. This occurred between all three international conventions (as all had a primary aim to protect the environment from IAS) as well as between the regional policy documents. The EU IAS Regulation for example had positive horizontal interactions with all European legislation. There was potential conflict between the Council Regulation concerning the use of alien and locally absent species in aquaculture, and European nature conservation policy such as the Habitat Directive and MSFD which recognise that IAS could prevent good environmental status being achieved. However, the Council Regulation only allows for alien species to be introduced or translocated after a series of applications, permits and monitoring which satisfies the aims of both Directives. Similar positive, neutral and negative horizontal interactions were found on a national scale between policies – with neutral interactions between marine and terrestrial policy.

3.5 Discussion

This study is the first to review the coherence of IAS policy in the marine environment and demonstrates positive linear consistency of policy from the three international conventions (Bern Convention, CBD and BWM Convention), and many positive interactions between policies horizontally and vertically. Our results illustrate that both the Bern Convention and CBD had been transposed into European and national law. The BWM Convention has not yet been transposed and is relatively new in comparison therefore any analysis for consistency was limited. In order to successfully manage IAS in the marine environment, policy instruments must be coherent as any failure in the chain could potentially weaken the overall effort to establish and maintain biosecurity (Lehtiniemi et al. 2015).

Regulation means that it applies directly without the need for member states to develop their own laws. Having a harmonised approach also makes it easier for organisations that operate in

multiple EU member states, to comply with one regulation as opposed to many. Therefore, there is opportunity for the BWM convention to be transposed on a European scale, which will make the implementation of the convention easier for stakeholders. Although in a time of uncertainty, as the UK leaves the EU, this may create issues. If the UK decide to implement the BWM convention separately to the EU, they must ensure that they positive interact and are consistent with EU legislation, as having conflicts between legislation between states can create opposition among stakeholders.

The specific terminology used by each Convention was consistently tracked within relevant European and national policy and all three conventions used different terminology for IAS. When looking at the definitions of each term in our study, the term 'invasive' was used to illustrate negative impacts, whilst the terms 'non-native' and 'alien' were used synonymously. However there is a shift in term from using the term 'IAS' on an international and European scale to using 'non-native' on a national level. Although not used within the analysis, the Great Britain Non-Native Species Strategy (which implements the EU IAS Regulation) shifts from using the CBD term 'alien' and instead inconsistently uses the term 'invasive non-native species'. This was in response to a study in 2008 conducted by Defra that found stakeholders (anglers, boaters etc) preferred the term 'INNS' and the term 'alien species' was less familiar and deemed a less appropriate term (Defra 2009). However, concerns around the definitions applied within international conventions have been raised by Richardson et al. (2000) who highlighted that whilst issues around definitions would unlikely be resolved, it would be imperative that international policy be consistent with the use of terminology, or if different terminology is preferred then definitions should be provided. Additionally, Larson (2005) argues that the type of terminology used to reference IAS can influence the management of a species or issues on the ground. Definitions were not always used within the policy documents, which could lead to confusion and misinterpretation. However, where definitions were provided, there were no conflicts between the terms 'IAS' and 'INNS' which both implied negative impacts.

Sectoral specific policies can potentially change behaviours of stakeholders because they are targeted at certain user groups and increase intention through perceived behavioural control of a certain behaviour (Ajzen 1999). In relation to sector specific IAS policies, policies address IAS issues specific to the industry (and pathway) and therefore have a greater potential to be more effective than general regulation/directives; this could potentially increase the uptake of behaviours to achieve the policy objective (Jacob and Volkery 2004). Sector specific policies must however positively interact with existing policies around the environment and society. Our results highlight a lack of positive vertical interaction between the BWM Convention and other policies. Therefore, we suggest that if the BWM Convention were transposed into

national legislation, it would be beneficial to analyse the vertical and horizontal interaction of these documents. Having a coherent horizontal framework (as well as vertical), is instrumental for the creation of a long-term holistic biosecurity model which will prioritise knowledge gaps within relevant sectors and contribute to the improvement of the reduction of IAS introductions (Hoey et al. 2016). Policy makers need to proactively engage the relevant commercial industries as part of the solution, as biosecurity can only occur with collaboration and cooperation from key pathway groups (i.e trade) (Reaser et al. 2008).

European regulation such as the EU IAS Regulation and the Regulation Concerning the use of Alien and Locally Absent Species in Aquaculture, are directly relevant at a national scale. On the other hand, there are Directives (Habitat Directive, WFD, MSFD) which have needed to be transposed into national legislation. The IAS Regulation can be directly applied without needed transposition on the national level which can explain the broad nature of the Regulation. Therefore, there is currently no specific national policy for the UK in relation to nationally specific IAS and biosecurity.

To address the lack of national legislation, the UK have created non-binding policy instruments which also implement the goals of international conventions and support regulatory instruments by setting out the values, standards of behaviour and expectations of stakeholders in order to achieve the aims of policy (Carter 2007). For example the Great Britain Non-Native Species Strategy is a national plan for Great Britain. In many cases, voluntary agreements come into place to avoid regulation. There are examples of voluntary agreements that are supported by governments and regulatory bodies; for example in the case in global climate change governance, voluntary agreements are officially endorsed by the United Nations Framework Convention on Climate Change (Gulbrandsen and Christensen 2014). In the case of IAS, voluntary codes of conduct and best practices are considered as fundamental flexible “implementation” tools which intend to mobilise a number of professionals linked to trade, exhibition, or sale of wild plants and animals (plus hunters, anglers and managers of protected areas). These voluntary codes are created to support public bodies, industry federations, user groups and/or NGOs in the hope that (due to existing interest) they will be the first to change behaviours to prevent the introduction and spread of IAS. In the case of IAS policy, there seemed to be a recent shift to sector specific voluntary instruments (codes of conduct, guidelines, strategies) to address IAS. For example, existing non-binding instruments include strategies (e.g. European Union Biodiversity Strategy, European Strategy on IAS) and codes of conduct (e.g. the European Code of Conduct on Zoological Gardens and Aquaria and IAS, the European Union Code of Conduct on Recreational Boating and IAS).

The combination of regulatory and voluntary instruments presents challenges to the coherence of IAS policy. Voluntary codes of conduct or best practice guidance should complement existing regulatory instruments and provide activity specific advice and incentives to stakeholders (Genovesi et al. 2015). The recent surge of voluntary instruments could suggest that top-down methods are inadequate and voluntary measures may be better suited for gaining acceptance and support (Tollington et al. 2015; Crowley et al. 2017). It will be necessary to measure the effectiveness of these instruments in relation to behaviour change to help policy makers understand what drives and motivates stakeholders to change behaviours in relation to IAS.

3.6 Conclusion

International conventions are part of and form global efforts to protect biodiversity and natural environments. IAS are a global problem that can pose a significant threat to the marine environment and therefore require a collaborative approach to manage. It is assumed that international policies set explicit aims and objectives which are then directly translated into action 'on the ground' through regional (European) and national instruments. It is important to evaluate the consistency of policy at each scale and understand the interactions between these policies, which will highlight any implications for their effectiveness. Through application of a top down policy analysis we were able to demonstrate that whilst regional and national instruments related to the same conventions were consistent, horizontal consistency and interaction was lacking between policy instruments, especially new emerging pathway specific policies. There is an opportunity for a more consistent approach to UK biosecurity across introductory pathways. Voluntary agreements should continue to work side by side of legislation however, the UK could learn from New Zealand's ambitious Biosecurity 2025 plan and adopt a Biosecurity Act or similar piece of legislation, which brings all the different sector instruments together to provide coherence and prevent any duplication of work. However, this will depend on more interaction and collaboration between sectors and industries and equally important is the existence of a specific central authority, an identifiable and responsible institution, to oversee and administer the process of strategic integration (Lafferty and Hovden 2003). Responsibility of these sectors to implement policy will increase coherence and create a stronger approach to managing IAS.

3.7 References

Ajzen. 1991. The theory of planned behaviour. *Organ Behav Hum Decis Process* 50:179–211.
doi: 10.1016/0749-5978(91)90020-T

Campbell M, Hewitt C. 2013. Protecting high-value areas from introduced marine species. *Manag Biol Invasions* 4:171–189. doi: 10.3391/mbi.2013.4.3.01

Carter N. 2007. *The Politics of the Environment*. Cambridge University Press, Cambridge, UK

Crowley SL, Hinchliffe S, McDonald RA. 2017. Invasive species management will benefit from social impact assessment. *J Appl Ecol* 54:351–357. doi: 10.1111/1365-2664.12817

Defra. 2009. *Wildlife Management and Invasive Non- Native Species: Report of Research Findings among the General Public, Anglers and the Horticultural Retail Trade (Volume 1)*. London, UK

Genovesi P, Carboneras C, Vilà M, Walton P. 2015. EU adopts innovative legislation on invasive species: a step towards a global response to biological invasions? *Biol Invasions* 17:1307–1311. doi: 10.1007/s10530-014-0817-8

Grosholz ED, Crafton RE, Fontana RE, et al. 2015. Aquaculture as a vector for marine invasions in California. *Biol Invasions* 17:1471–1484. doi: 10.1007/s10530-014-0808-9

Gulbrandsen LH, Christensen AR. 2014. EU legislation to reduce carbon emissions from cars: Intergovernmental or supranational policy making? *Rev Policy Res* 31:503–528. doi: 10.1111/ropr.12100

Hoey J, Campbell M, Hewitt C, et al. 2016. *Acanthaster planci* invasions: applying biosecurity practices to manage a native boom and bust coral pest in Australia. *Manag Biol Invasions* 7:213–220. doi: 10.3391/mbi.2016.7.3.01

Höhne N, Kuramochi T, Warnecke C, et al. 2017. The Paris Agreement: resolving the inconsistency between global goals and national contributions. *Clim Policy* 17:16–32. doi: 10.1080/14693062.2016.1218320

Howlett M, Rayner J. 2007. Design Principles for Policy Mixes : Cohesion and Coherence in ‘ New Governance Arrangements .’ *Policy Soc* 26:1–18. doi: 10.1016/S1449-4035(07)70118-2

Hulme PE, Bacher S, Kenis M, et al. 2008. Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *J Appl Ecol* 45:403–414. doi: 10.1111/j.1365-2664.2007.01442.x

Hulme PE, Bacher S, Kenis M, et al. 2016. Blurring Alien Introduction Pathways Risks Losing the Focus on Invasive Species Policy. *Conserv Lett* 10:265–266. doi: 10.1111/conl.12262

IMO. 2011. Resolution MEPC.207(62)- 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. London, UK

Jacob K, Volkery A. 2004. Institutions and Instruments for Government Self- Regulation: Environmental Policy Integration in a Cross-Country Perspective. *J Comp Policy Anal Res Pract* 6:291–309. doi: 10.1080/1387698042000305211

Kalaba FK, Quinn CH, Dougill AJ. 2014. Policy coherence and interplay between Zambia's forest, energy, agricultural and climate change policies and multilateral environmental agreements. *Int Environ Agreements Polit Law Econ* 14:181–198. doi: 10.1007/s10784-013-9236-z

Katsanevakis S, Zenetos A, Belchior C, Cardoso AC. 2013. Invading European Seas: Assessing pathways of introduction of marine aliens. *Ocean Coast Manag* 76:64–74. doi: 10.1016/j.ocecoaman.2013.02.024

Kettunen M, Genovesi P, Gollasch S, et al. 2009. Technical support to EU strategy on invasive alien species (IAS) - Assessment of the impacts of IAS in Europe and the EU (final module report for the European Commission). Brussels, Belgium

Kivimaa P, Virkamäki V. 2014. Policy mixes, policy interplay and low carbon transitions: The case of passenger transport in Finland. *Environ Policy Gov* 24:28–41. doi: 10.1002/eet.1629

Lafferty W, Hovden E. 2003. Environmental policy integration : towards an analytical framework. *Env Polit* 12:1–22. doi: 10.1080/09644010412331308254

Larson BMH. 2005. The war of the roses: Demilitarizing invasion biology. *Front Ecol Environ* 3:495–500. doi: 10.1890/1540-9295(2005)003[0495:TWOTRD]2.0.CO;2

Lehtiniemi M, Ojaveer H, David M, et al. 2015. Dose of truth-Monitoring marine non-indigenous species to serve legislative requirements. *Mar Policy* 54:26–35. doi: 10.1016/j.marpol.2014.12.015

Lucas K, Brooks M, Darnton A, Jones JE. 2008. Promoting pro-environmental behaviour : existing evidence and policy implications. *Environ Sci Policy* 11:456–466. doi: 10.1016/j.envsci.2008.03.001

May PJ, Sapotichne J, Workman S. 2006. Policy coherence and policy domains. *Policy Stud J* 34:381–403. doi: 10.1111/j.1541-0072.2006.00178.x

- Moura P, Garaulet LL, Vasconcelos P, et al. 2017. Age and growth of a highly successful invasive species: the Manila clam *Ruditapes philippinarum* (Adams & Reeve, 1850) in the Tagus Estuary (Portugal). *Aquat Invasions* 12:133–146. doi: 10.3391/ai.2017.12.2.02
- Nilsson M, Zamparutti T, Petersen JE, et al. 2012. Understanding Policy Coherence: Analytical Framework and Examples of Sector-Environment Policy Interactions in the EU. *Environ Policy Gov* 22:395–423. doi: 10.1002/eet.1589
- Nunes AL, Tricarico E, Panov VE, et al. 2015. Pathways and gateways of freshwater invasions in Europe. *Aquat Invasions* 10:359–370. doi: 10.3391/ai.2015.10.4.01
- Owens S, Driffill L. 2008. How to change attitudes and behaviours in the context of energy. *Energy Policy* 36:4412–4418. doi: 10.1016/j.enpol.2008.09.031
- Pimentel D, Zuniga R, Morrison D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecol Econ* 52:273–288. doi: 10.1016/j.ecolecon.2004.10.002
- Reaser JK, Meyerson LA, von Holle B. 2008. Saving camels from straws: How propagule pressure-based prevention policies can reduce the risk of biological invasion. *Biol Invasions* 10:1085–1098. doi: 10.1007/s10530-007-9186-x
- Ricciardi A, MacIsaac HJ. 2010. Impacts of Biological Invasions on Freshwater Ecosystems. In: *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*. Blackwell Publishing Ltd, Sussex, UK, pp 211–224
- Richardson DM, Pyšek P, Rejmánek M, et al. 2000. Naturalization and invasion of alien plants: Concepts and definitions. *Divers Distrib* 6:93–107. doi: 10.1046/j.1472-4642.2000.00083.x
- Sambrook K, Holt RHF, Sharp R, et al. 2014. Capacity, capability and cross-border challenges associated with marine eradication programmes in Europe: The attempted eradication of an invasive non-native ascidian, *Didemnum vexillum* in Wales, United Kingdom. *Mar Policy* 48:51–58. doi: 10.1016/j.marpol.2014.03.018
- Santos G, Behrendt H, Teytelboym A. 2010. Research in Transportation Economics Part II : Policy instruments for sustainable road transport q. *Res Transp Econ* 28:46–91. doi: 10.1016/j.retrec.2010.03.002

- Schillo RS, Isabelle DA, Shakiba A. 2017. Linking advanced biofuels policies with stakeholder interests: A method building on Quality Function Deployment. *Energy Policy* 100:126–137. doi: 10.1016/j.enpol.2016.09.056
- Schreier M. 2012. *Qualitative Content Analysis in Practice*. SAGE Publications, London, UK
- Strambo C, Nilsson M, Månsson A. 2015. Coherent or inconsistent? Assessing energy security and climate policy interaction within the European Union. *Energy Res Soc Sci* 8:1–12. doi: 10.1016/j.erss.2015.04.004
- Tidbury HJ, Taylor NGH, Copp GH, et al. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biol Invasions* 18:3277–3292. doi: 10.1007/s10530-016-1219-x
- Tollington S, Turbé A, Rabitsch W, et al. 2015. Making the EU Legislation on Invasive Species a Conservation Success. *Conserv Lett* 10:112–120. doi: 10.1111/conl.12214
- Urwin K, Jordan A. 2008. Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. *Glob Environ Chang* 18:180–191. doi: 10.1016/j.gloenvcha.2007.08.002
- Williams F, Eschen R, Harris A, et al. 2010. *The Economic Cost of Invasive Non-Native Species on Great Britain*. Oxford, UK
- Williams SL, Grosholz ED. 2008. The invasive species challenge in estuarine and coastal environments: Marrying management and science. *Estuaries and Coasts* 31:3–20. doi: 10.1007/s12237-007-9031-6

Chapter 4: Getting on board with biosecurity: Evaluating the effectiveness of marine invasive alien species biosecurity policy for England and Wales

4.1 Abstract

Marine Invasive Alien Species (IAS) can have devastating impacts on the environment, on infrastructure and on human well-being with the Convention on Biological Diversity (CBD) recognising that there is an urgent need to address the issue of IAS. Prevention measures including biosecurity are essential to reducing the risk of introduction and spread of IAS but rely on positive changes in behaviour which can be difficult and often depends on a combination of interventions. Policy instruments attempt to change behaviour through establishing rules or principles through laws or voluntary agreements. Understanding the motivations of stakeholders can help determine whether policy instruments are effective at encouraging positive behaviour change, and if these behaviours are effective at reducing the risk from IAS. A total of 14 semi-structured interviews were conducted among two case study groups in England and Wales (marine shellfish aquaculture industry and the recreational boating sector), to evaluate motivations for behaviour and reasons for undertaking biosecurity in order to understand policy instrument effectiveness. Biosecurity practices were deeply embedded in the heavily regulated practices to control shellfish disease within the shellfish industry; motivations to undertake biosecurity were driven by economic incentives, and penalties for disease control. In contrast, there were little regulatory policy instruments to drive IAS biosecurity within the recreational boating sector, which instead relied heavily on voluntary instruments to motivate stakeholders and encourage behaviour change; however, behaviour change was restricted by lack of infrastructure and enforcement. Our findings suggest it is important to use a combination of policy instruments to achieve behaviour change, but recognising that where regulations and penalties cannot be enforced, voluntary instruments are likely to be more effective if they address existing social norms and investment in infrastructure should 'nudge' individuals into socially desirable behaviours. For policy makers and regulators, this research reveals the importance of tailoring behaviour change strategies to different stakeholder groups as those undertaking different activities are motivated by different factors.

4.2 Introduction

Invasive Alien Species (IAS) (also known as invasive non-native species (INNS)) are broadly defined as species that have been moved into new areas (terrestrial, freshwater and marine) outside of their natural range by human activities (intentionally or unintentionally), and can

have negative ecological, economic or social impacts (Simberloff et al. 2013). According to the Convention on Biological Diversity (CBD), IAS are considered to be one of the main drivers of biodiversity loss across the globe (Roy et al. 2012b). Negative impacts of IAS in the marine environment include restricting navigation, clogging propellers and affecting aquaculture stocks as marine IAS smother the hard structures on which they grow (Williams et al. 2010b; Katsanevakis et al. 2013b; Minchin et al. 2013a). In the European Union (EU), IAS are estimated to cost approximately €12.5 billion a year (Kettunen et al. 2009), and in Great Britain £1.7 billion a year (Williams et al. 2010b). The current estimate of the annual combined UK and Ireland cost is £2 billion (Kelly et al. 2013). It has also been estimated that the direct cost of IAS to marine industries in Great Britain is approximately £40 million per year (Williams et al. 2010).

In the marine environment non-native species are intentionally introduced for aquaculture farming but can potentially escape and spread into the wild and become invasive. For example, *Ruditapes philippinarum* (manila clam) was introduced into England in the 1980s for aquaculture and by 2010 the species had escaped and naturalised in Southern England (Humphreys et al. 2015). Similarly, *Magallana gigas* (Pacific oyster) was introduced into England first in 1890 and again in 1960 to counteract the decline of the native oyster and improve the oyster industry (Humphreys et al. 2014). However, since its deliberate introduction, wild settlements of Pacific oysters have now been discovered in European protected areas, which could impact the condition of the site (Herbert et al. 2016). In contrast, some IAS are introduced unintentionally, for example *Sargassum muticum* (invasive wireweed) was accidentally introduced with imported commercial oysters (either attached to boats or attached to shellfish) and since its introduction has had negative environmental and economic impacts through fouling oyster beds and fishing gear, acting as a nuisance in harbours and increasing costs to businesses to remove (Critchley et al. 1986; Williams et al. 2010). Boats and ships may also accidentally introduce IAS through ballast or as biofouling and also act as vectors of secondary spread (i.e. attached to hulls, anchor chains and other parts of the vessel). Ballast water and hull fouling are likely pathways for the unintentional introduction of the invasive *Didemnum vexillum* (carpet sea squirt) in England and Wales (Griffith et al. 2009) which can grow and smother native reef habitats and cost mussel farming in Great Britain between £1.3 and £6.8 million due to cleaning costs to vessels and equipment (Williams et al. 2010b; Minchin et al. 2013b). Preventing the unintentional introduction and spread of marine IAS is therefore extremely important to prioritise in an attempt to minimise the cost of control and eradication. Prevention is recognised by the CBD as one of the most cost-effective methods to reduce the risks that IAS pose and states that 'each contracting Party shall, as far

as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species'. Prevention can occur at different stages, such as identifying and targeting introduction pathways, intercepting movements at borders, and improving ballast water treatment to stop unintentional introductions through shipping (Simberloff et al. 2013; Macleod et al. 2014). Biosecurity is a collective term that refers to the practices, routines, technologies and measures that are designed to prevent the introduction and secondary spread of IAS (Reed and Curzon 2015). Preventing the introduction and secondary spread of IAS through employing biosecurity measures therefore relies on changes in human behaviour.

Knowledge is often seen as key to changing behaviour; if an individual does not know about their impacts of their actions then they cannot be expected to change their behaviour. In the case of IAS, Eiswerth et al. (2011) found that knowledge (or awareness) of IAS was an important antecedent to participation in biosecurity behaviours to reduce IAS spread. Similarly, Seekamp et al. (2016) found that knowledge and awareness of IAS was significantly related to prevention behaviours. However, Schultz (2002) argues that it is not knowledge alone that provides a motive for behaviour, but instead that a lack of knowledge is a barrier to behaviour and other factors are responsible for direct changes in behaviour. Attitudes are often linked to knowledge as it is assumed that as an individual becomes more knowledgeable about an issue, their attitude will become more positive and thus in turn become more motivated to act toward the environment in more responsible ways (Hungerford and Volk 1990; Rothlisberger et al. 2010; McKenzie-Mohr and Schultz 2014).

According to Ajzen's Theory of Planned Behaviour, attitudes toward behaviour, subjective norms and perceived behavioural control shape an individual's behavioural intentions and behaviours (1991). There has been an increased research exploring and evaluating public attitudes towards and support for IAS management (including prevention). For example, Humair et al. (2014) found that horticulturalist's attitudes towards regulations were supportive which in turn lead to participants reporting that they were also willing to engage in various voluntary actions to mitigate invasion risks from non-native ornamentals. Similarly, Wald et al. (2019) found that public attitudes toward IAS management lead to public support for conservation action. On the other hand, despite high levels of awareness of regulations and supportive attitudes among horticultural industry managers, Cronin et al. (2017) found that actual compliance with the regulations was low and many nurseries were stocking regulated IAS and several factors were quoted as constraints on compliance by the industry. Trust, communication, enforcement and experience are just a few important determinants of

attitude (Cronin et al. 2017; Wald et al. 2019). Therefore, single constructs such as attitudes cannot accurately predict behaviour but are an important factor.

Subjective norms (the perceived social pressure to perform a behaviour) are another component to the Theory of Planned Behaviour (Ajzen 1999). Perceived social pressure will also influence if people perform a certain behaviour. Social norms are also an important factor that influence a persons' intention to carry out a behaviour and can often be used to influence and encourage behaviour change (Abrahamse and Steg 2013). Social norms are predominant behavioural patterns within a group that are supported by a shared understanding of acceptable actions, sustained through social interactions (Nyborg et al. 2016). Social norms rest on the assumption that people want to fit in with what most people do and what 'should be done' and therefore rely on having a smaller community size so individuals are more likely to change norms in line with the community (Cialdini et al. 1990; Abrahamse and Steg 2013). For example, within the plant and animal farming sector, Mankad (2016) found that social norms were a strong predictor of biosecurity engagement as individual were more likely to undertake biosecurity when they perceived a social consequence. Social norms may also play an important role within the marine environment where different groups/activities may have shared norms that influence behaviour (Mankad 2016).

Changing behaviour depends on a combination of tools and interventions (e.g. education, training, policy instruments, and incentives) which aim to increase perceived behavioural control and intention to behave (Ajzen 1999; Michie et al. 2011; Cronin et al. 2017). Interventions and tools attempt to increase knowledge and awareness around particular issues and create positive attitudes towards management. Policy instruments are tools that attempt to change behaviour through establishing rules or principles through implementing laws or voluntary agreements. Since policy instruments attempt to change behaviour, understanding stakeholders' knowledge and attitudes towards IAS and policy instruments and the motivations to change behaviours is critical to successful policy planning and implementation. Previous studies have found that a better understanding of stakeholders' knowledge, attitudes and motivations have aided and supported the creation of effective IAS policy campaigns and strategies (Polonsky et al. 2004; Prinbeck et al. 2011; Floerl et al. 2016). Stakeholders may be motivated by the policy instruments themselves or by other human dimensions such as their beliefs, values, economic incentives, social pressures (Kollmuss and Agyeman 2002; Prinbeck et al. 2011).

Understanding knowledge and attitudes of IAS policy instruments and motivations to undertake biosecurity among stakeholders can help determine the effectiveness of policy instruments, as it determines the drivers (policy or non-policy) of behaviour (Michie and West 2013; Mankad 2016). Understanding the knowledge, attitudes and motivations of stakeholders will help inform the creation of effective future IAS campaigns and policy to increase an individuals' perceived behavioural control to perform the behaviour. Since the implementation of IAS regulatory and voluntary instruments, there has been no evaluation on the efficacy and effectiveness of these instruments in relation to biosecurity behaviours of stakeholders in the marine environment in the UK (specifically England and Wales). Further understanding of what influences an individual's motives to undertake (or not undertake) biosecurity measures may help to better inform the future management of marine IAS. To investigate this, semi-structured interviews can be used to allow participants to diverge into related topics and allows insights that might otherwise be missed using questionnaires (Morgan 2011). Using two marine case studies in England and Wales (the shellfish industry and the recreational boating sector) the current study determines the effectiveness of existing policy and policy instruments on behaviours within the marine environment using semi-structured interviews. The study has two goals: (1) to reveal motivations for undertaking biosecurity and understand whether this is as a result of policy instruments or other factors (2) to understand what extent the current actions undertaken are achieving the goals of good biosecurity practice. Whilst these case studies do not directly compare, the two cases are still able to highlight useful differences in motivations for behaviour and reasons for undertaking biosecurity which may illustrate differences in policy implementation success.

4.3 Methodology

4.3.1 Study area

This research focuses on England and Wales only as they are covered by the same policy framework and excludes Northern Ireland and Scotland which are covered by different political systems and policies dealing with marine IAS. A combination of regulatory and voluntary instruments are used to address the introduction and mitigate the impacts of IAS in the marine environment (Appendix F). These instruments either directly relate to IAS and their pathways or affect them indirectly through targeting conservation actions. First, regulatory policy instruments in the marine environment either directly manage the impacts and risk of IAS or certain pathways. As a contracting party to the CBD, and as a member state of the EU the UK has implemented various regulatory and voluntary policy instruments to meet the objectives of the CBD. The EU Regulation 1143/2014 on IAS establishes an EU-wide framework to achieve the goals of the CBD to prevent, minimise and mitigate the adverse impacts of IAS on

biodiversity, and centres on the development of a list of IAS of EU Concern. The Regulation is a binding agreement within the EU and places strict restrictions and obligations on member states to reduce the impact of IAS. In Great Britain (England, Scotland and Wales), the goals of the EU Regulation are implemented through the Great Britain Non-Native Species Strategy which provides a strategic framework for coordinating government and stakeholders to address the impacts of IAS. Regulation is also used to manage certain activities in the marine environment, including aquaculture. For example, the Aquatic Animal Health Regulations (2009) and the Alien and Locally Absent Species in Aquaculture Regulations (2011) aim to prevent, monitor and control certain diseases in aquatic animals as well as managing the risk of accidental escape. However, the primary goal of regulation in the shellfish industry is to regulate activities in relation to aquatic animal health as opposed to the management of IAS.

Voluntary initiatives are also used to supplement, complement or replace direct government regulation (Hulme et al. 2017). Voluntary instruments include strategies, codes of conduct and campaigns which attempt to shift the focus from relying on laws and regulations to education and awareness raising (Vander Zanden and Olden 2008). In the case of IAS, the European Code of Conduct on Recreational Boating and IAS (2016) supports the aims of the EU Regulation (1143/2014) to encourage recreational boaters to apply preventative measures to reduce the risk of accidentally spreading IAS. Also in the UK, campaigns such as *Be Plant Wise* and *Check Clean Dry* promote IAS awareness and good practice for activities in the freshwater aquatic environment.

4.3.2 Case study 1: Shellfish industry

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, shellfish and aquatic plants under controlled conditions (FAO 2019). Shellfish farming is based on the collection of wild or hatchery larvae, which feed on natural nutrients found in the environment (filter-feeding animals) (Laing et al. 2004). Oyster and mussel farming account for 90% of European shellfish production and use a wide range of techniques: bottom-farming, on tables, wooden posts, ropes, etc. (Ellis et al. 2015). Shellfish contribute nearly 50% of the total value of seafood landed into the UK, and cultivated shellfish contribute an additional £38 million, from nearly 30,000 tonnes (SAGB 2019). In 2012, Wales produced the highest tonnage of shellfish in the UK (8999 tonnes), but the English industry had a higher value due to the higher unit price of Pacific oysters (£10 million) (Ellis et al. 2015). Aquaculture activities such as the movement of shellfish stock or equipment have been identified as potential introductory pathways for numerous IAS (Tidbury et al. 2016; Cottier-Cook et al. 2019). For example, the non-native Pacific oyster is heavily farmed in England but has the potential to accidentally escape into the wild, which can

often lead to devastating environmental, economic and social impacts (Williamson and Fitter 1996; Schlag 2010; Humphreys et al. 2014).

4.3.3 Case study 2: Recreational boating sector

Recreational boating refers to all forms of water craft used for personal use, including dinghy and yacht racing and personal watercraft used for travel (RYA 2017). In Europe there are estimated to be around 36 million boaters, and in the UK 1.13 million boats/watercraft; of this, 541,000 are leisure boats which are estimated to contribute £1.3 billion per annum to the economy (RYA 2014). The recreational boating sector is also identified as a significant vector for the introduction and spread of non-native species, especially at more local scales, allowing the secondary spread of these species away from sites of first introduction (Delabbio et al. 2005; Roche et al. 2015; Ferrario et al. 2016; Ventura et al. 2016). Recreational vessels can transport IAS via hull fouling, internal fouling in pipes, in ballast, bilge or anchor-well water, and in inlets leading off the hull (Acosta and Forrest 2009; Ferrario et al. 2016; Tidbury et al. 2016). As a boat moves from and between each new area (nationally and internationally), it may carry IAS or propagules that can detach or be deposited in the new environment (Rothlisberger et al. 2010). Marinas can also provide a suitable environment for IAS colonisation and therefore act as a reservoir for IAS to grow and spread further (Glasby et al. 2007; Roche et al. 2015). Smaller watercraft may also be transported overland to a new waterbody carrying potential IAS (Rothlisberger et al. 2010). Marine IAS may also impact on recreational boating directly, for example hull fouling species such as *Dreissena polymorpha* (Zebra mussel) and *Dreissena rostriformis bugensis* (Quagga mussel) can attach onto the hull of a boat which can increase maintenance costs, affect navigation and sometimes be damaging to the boat itself (Ventura et al. 2016).

4.3.4 Sampling

We applied mixed methods to stakeholder identification; predefined categories and snowball sampling. First, predefined categories were used to focus the stakeholder identification process to the research aim and allow a representative sample to be identified. The predefined categories included: local councils, regulators, marine governing bodies, initiatives/campaign organisers, scientific research, conservation body/authority and industry (owners and managers). These categories were applied to both case studies.

The research team searched existing policy and policy instruments (identified in Chapter 3) for names and organisations of relevance. If no name was given but an organisation was, the researchers used an online search to identify relevant individuals. Participants within

organisations were identified by their job description as those that had an interest in biosecurity due to their role (Colvin et al. 2016). In addition to the policy document and online search, the research team (which includes regulators and academics) used their own knowledge and existing contacts in this field to identify organisations and individuals that would be affected by or have an interest in biosecurity.

We aimed to identify and approach at least one organisation/individual in each category. All individuals from the initial stakeholder identification (identified participants $n=25$) were invited by e-mail to take part (Table 4.1). Those that accepted were sent an information sheet (Appendix G) about the project one week prior to interview and were also given the opportunity to read this again before the interview began. Informed consent was obtained on the day of interview (Appendix H) and the study satisfied the University of Leeds' guidelines on ethical conduct (Ethics reference AREA 14-121) with regards to anonymity and confidentiality for research participants.

After each interview was complete, participants were asked to identify any contacts that they considered relevant to the study (snowball sampling) (snowball sampling increased the total of identified participants to $n=30$). This, in combination with the original list developed by the researchers, was used to identify further respondents and reduce bias in stakeholder identification. Interviews continued until a saturation point was reached where no new participants were identified and all approached participants had either been interviewed or had declined (Reed et al. 2009; Guest et al. 2012).

Table 4.1 Identified and final interview participants according to pre-defined categories

	Recreational Boating Sector		Shellfish Industry	
	Identified participants ($n=16$)	Final interview participants ($n=8$)	Identified participants ($n=14$)	Final interview participants ($n=6$)
Local Council	3	1	2	
Regulators	1	1	2	1
Governing bodies	2	2	1	1
Initiatives/campaign organisers	2	1	1	
Scientific research	2	1	1	
Conservation body/authority	2	1	2	1
Industry (owners and managers)	4	1	5	3

4.3.5 Interview process

We applied a qualitative approach to data collection and data analysis, which allows for a deeper evaluation of the drivers and motivations of stakeholders, and the effectiveness of biosecurity policy implementation in the marine environment. We devised a semi-structured interview topic guide that was organised around three sections (plus an introductory information section) related to the objectives of the study (Appendix I). Standardised open-ended questions were organised under these sections. The topic guide allowed the interviewer to guide the discussion around the questions, and remained sensitive to the fact that participants' initial understandings and opinions may change as the interview progresses (Morgan 2011). The first topic explored was the participant's activities undertaken in the marine environment allowing the participants to draw on experience of IAS and biosecurity practices; this topic was covered first to enable respondents to identify actual biosecurity practices without being influenced by the content of subsequent topics. The second topic related to knowledge (or awareness) of policy and policy instruments related to the marine environment and IAS, in addition to their attitudes toward policy and policy instruments. The third topic related to motivations for carrying out biosecurity and attitudes/feelings towards biosecurity advice/behaviour and if there were any consequences to not undertaking biosecurity. If suggestions/probes/prompts were needed to encourage the participant to speak about the topic, the same suggestions were used consistently with each participant to allow for greater comparability between interviews.

Following pilot testing of the interview questions, a total of 14 semi-structured interviews were conducted between March and May 2018 with stakeholders from the recreational boating sector (n=8) and stakeholders within the marine shellfish industry (n=6). All interviews were conducted and transcribed by the PhD researcher. Conversations ranged from 45 minutes to 1 hour and were audio recorded for transcription.

4.3.6 Data analysis

This study implemented a constant comparative method following a Straussian grounded theory approach (Strauss and Corbin 1990) for data analysis. After the interviews were transcribed, the researcher examined the transcripts in depth and line by line using an open coding method which involved generation of descriptive labels in which text fragments received one or more labels which covered the content as well as possible concepts in order to elaborate a deeper understanding of the text (Bhattacharjee 2012). Annotations and

concepts (codes) were applied to single words and short sentences to identify events, incidents, ideas, actions, perceptions, similarities, differences and interactions of relevance (in vivo codes) (Ryan and Bernard 2003; Bhattacharjee 2012). In grounded theory, coding is used to help compare data set to data set, which in this case was the comparison of interview to interview.

Similar codes were retrieved and grouped into broad categories. These categories were: policy, conflicts, action and motivation. This process moved from describing the data to interpretation. Axial coding was then used to establish linkages between categories, some pre-determined from the literature review with others emerging from the data (Bhattacharjee 2012; Howard-Payne 2016). Constant comparative analysis was applied until theoretical saturation was reached and no new codes, concepts or categories emerged from the data.

4.4 Results

In the following sections, we discuss the motivational factors within both case studies that drive biosecurity behaviour.

4.4.1 Motivational factor: Policy instruments

Participants from the shellfish industry agreed that their activities were heavily regulated. Regulations for disease control were strictly enforced and so this affected biosecurity more than regulations for IAS. Participants in the shellfish industry gave examples of the Aquatic Animal Health (England and Wales) Regulation (2009) and the Alien and Locally Absent Species in Aquaculture (England and Wales) Regulation (2011) as being particularly important determinants of behaviour within the industry. These regulations were used to regulate their activities and promote biosecurity behaviour to prevent the accidental escape of IAS or introduction and spread of disease in aquaculture. The shellfish industry is required under the Aquatic Animal Health Regulations (2009) to implement a biosecurity measures plan to prevent disease spread. The Shellfish Biosecurity Measures Plan has been provided by the regulators (Cefas) to help businesses identify biosecurity measures applicable to their individual site. Participants were motivated to follow the regulatory advice because the consequences of a disease outbreak would include economic damage, reputational damage and loss of business.

In contrast, participants from the recreational boating sector recognised that there was no direct regulation related to their activities including any that were related to IAS and

biosecurity. Any regulatory instruments that did exist were only selective for certain boats and activities rather than for the whole sector (e.g. ballast water guidelines for shipping). Nonetheless, they were aware of regulations such as the EU IAS Regulation (1143/2014) and the Marine Strategy Framework Directive (MSFD) (2008), but recognised that these existing regulatory instruments were not specific to recreational boating activities. Therefore motivation to undertake biosecurity was not in response to regulatory instruments.

Voluntary instruments to manage IAS were used by both case study groups. Some regions had created local voluntary biosecurity plans for stakeholders to address the issues of IAS in the marine environment. These plans promoted biosecurity measures aimed at preventing the introduction and spread of IAS for both the shellfish industry and the recreational boating sector. Plans highlighted the need for prevention and rapid response to IAS and disease in the marine environment and attempt to encourage a coordinated approach to management.

Where regional biosecurity plans exist, participants from the shellfish industry were aware of the plans as many had taken part in the creation process. Those participants expressed that they were happy to work alongside regulators and other stakeholders to produce regional and local voluntary advice for IAS biosecurity, mostly in an attempt to avoid further regulations for the industry. In addition to this, participants believed that there were additional benefits to being involved in the process. These participants expressed that involvement 'looked good' for their business and there was potential to build a good rapport with the regulators.

Participant 10: We're quite happy to work with X and X... Plus we want them to be on our side and it usually looks good when we work with them! We are the ones that know the business the best!

These regional voluntary plans for IAS and disease biosecurity centre on the *Check Clean Dry* campaign. The *Check Clean Dry* routine was considered to be a normal routine in the shellfish industry. Therefore all participants were supportive of the campaign, as they believed the advice was simple to implement and they considered it to be no different to activities they carried out in response to regulatory measures for disease. Some participants also considered the advice to be 'common sense'.

Participant 10: We do that anyway! And that was how we shaped the advice. What I needed to do with the advice was make sure it was already done anyway and there was no stupid nonsense.

Due to a lack of regulatory instruments for recreational boating, there was a reliance on voluntary instruments to address biosecurity and IAS. Participants in this sector were also aware of regional biosecurity plans (where regional plans existed) and were also aware of the *Check Clean Dry* campaign and voluntary policy instruments such as the EU code of conduct on recreational boating and IAS (2016). Because recreational boating is recognised as a possible vector for the accidental spread of IAS, the code of conduct was designed to provide voluntary best practice guidelines to the industry to reduce the risk of spread. However, although the code of conduct was implemented in 2016, alongside regional biosecurity plans, participants were unsure whether voluntary guidance was actually effective because of issues with practicality and economic barriers.

Nonetheless, similar to the shellfish industry, participants from the recreational boating sector were motivated to support these voluntary instruments because they wanted to avoid further regulation. However, there was a general consensus among participants that the boating sector would be too difficult to regulate as no individual could be made accountable for an introduction of IAS.

4.4.2 Other motivational factors

A range of other factors that affected peoples motivations emerged from analysis including; practicality, experience, responsibility and reputation, economic factors, conflicting advice and social norms.

4.4.2.1 Practicality

Practicality was described by participants as having the right infrastructure in place to carry out biosecurity practices as well as adequate enforcement to check uptake and practice.

There were no practicality issues identified within the shellfish industry. Much of the infrastructure to implement biosecurity for IAS (e.g. facilities to check, clean and dry equipment) was already in place due to existing procedures for shellfish disease required as a result of regulatory requirements.

However, in the recreational boating sector participants felt that there was a lack of infrastructure to clean boats, as well as issues with enforcement. Whilst participants were supportive of the aims of the *Check Clean Dry* campaign, they felt that in reality there would be few individuals actually cleaning boats because of a lack of infrastructure. In addition, the advice from the campaign was considered impractical for certain boat types as some cannot be removed from the water to clean. Nonetheless, where advice focussed on being as practical as

possible and promoted checking and drying boats, this was recognised as something some boaters already did.

Participant 1: They haven't said they won't, but they have said it is impractical. So we have emphasised that one of the most important things to do is to dry your boat out, which they can do and they do anyway, leave it at least a couple of weeks before you use it.

In addition to infrastructure acting as a barrier to uptake of biosecurity, participants argued that the only time any cleaning measures would actually be done was either when participants wanted to maintain their boat or if it was a requirement of a site/organisation where enforcement could be applied (e.g. during competitions or in certain high-risk areas with existing byelaws and wash down sites). However, consistent enforcement was considered to be too difficult, as without regulation, there was currently no punishment. Therefore any enforcement was impractical.

Participant 5: Once you put a marine biosecurity procedure in place, someone should be in charge of it. But you still can't force the people using the marina to play by the rules. The marina can only give the message across and do the best they can with biosecurity, but they can't punish, or enforce anything on the individual boat owner.

The final practicality issue with biosecurity for recreational boaters was due to the nature of recreational boating, many boaters did not use the same site daily, and many used multiple locations and sites in a day or a week. Therefore the practicality of cleaning and enforcing cleaning was considered to be even more difficult.

4.4.2.2 Experience

Experience was an important motivation to undertake biosecurity measures within the shellfish industry. The small size of the industry and the close networks of members meant that experience of previous outbreaks was often shared. Participants gave examples of previous IAS outbreaks, not just on their own farms, but on farms close by; including *Sargassum muticum* (invasive wireweed), *Corella eumyota* (orange-tipped sea squirt), and *Didemnum vexillum* (carpet sea squirt). These outbreaks increased perceptions of risk and motivated individuals to undertake biosecurity practices.

In contrast to the shellfish industry, there was a lack of experience and limited examples of IAS outbreaks directly impacting the recreational boating sector. Whilst participants gave examples of IAS that could potentially pose a threat to the marine environment, many

participants could not give examples of the impact they had on recreational boating in England and Wales and there were no known recent outbreaks. A lack of experience (and evidence) acted as a disincentive to behaviour change.

*Participant 2: It is so difficult isn't it? When you have got litter, you can see it as an issue. But it is so difficult to explain invasive species as an issue when you can't see it and when there is no evidence. And the examples have to be in this country as well. You can show examples of *Didemnum vexillum* in New Zealand but... it's not relevant.*

Participants recognised that due to this lack of experience, any practice was likely to be reactive in response to an outbreak rather than preventative in terms of biosecurity.

4.4.2.3 Responsibility and reputation

Participants within the shellfish industry were motivated to undertake biosecurity as they felt a sense of responsibility to neighbouring farms. The small size and connectedness of the industry, meant outbreaks (of disease or IAS) could be traced. Therefore it was considered to be a community issue if there was an outbreak. If there was an issue with one farm, then there was potential for other farms to be affected and potentially close to prevent the risk of spread. Therefore each farm had a responsibility to neighbouring farms to practice good biosecurity.

Participant 9: Yes, for me it is common sense but if anything goes wrong you are the one responsible for it. Which in this industry that is the main thing. If there is someone to blame then they will look for that.

Participants also indicated that there was an element of commercial reputation motivating them to undertake biosecurity, as participants within the shellfish industry recognised that to help sell their products they needed to be seen to employ best practice.

Participant 9: Well ... We want to be setting the standard in the industry rather than following suit. We have got quite a bit of money behind us now, and we want to be the industry leaders and used as an example.

Similarly, some organisations within the recreational boating sector were also motivated to promote biosecurity to improve their reputation, and believed they were responsible as an organisation to be seen to be doing something. Some larger boating organisations recognised that they had a responsibility to address environmental issues such as plastics, sustainability, and IAS. Promoting awareness of a range of environmental issues together was the usual approach used by individual organisations, as many believed IAS alone would

not be treated as a priority issue. Regulatory and member-based organisations took measures to promote the *Check Clean Dry* campaign and collaborate with smaller organisations to produce guidance documents and management plans focussed on certain boating activities. However, in comparison to the shellfish industry, participants from the recreational boating sector felt there was little individual responsibility to undertake biosecurity.

4.4.2.4 Economic factors

Motivation to undertake biosecurity in the shellfish industry was keenly driven by economic consequences. Economic consequences included; loss of stock, large fines, and the potential for their farm to be shut down. Regulation for disease control motivated biosecurity to avoid economic consequences, however, participants considered the consequences for disease and IAS to be the same. Therefore, motivation for undertaking IAS biosecurity was again a co-benefit of undertaking biosecurity for disease.

However, there were also economic costs to undertaking the 'cleaning' phase of biosecurity in the shellfish industry, for example one farmer discussed:

Participant 9: So we have implemented an EA application, so when we pump out our water... This is ridiculous... We pump the water out of the river, then we wash the shells off with the water. But we have to pay £8000 a year to put it back in!

Nonetheless, the consequences of not following the rules were considered too high and even when there were some economic costs to biosecurity, they were obliged to follow the rules and advice due to regulatory consequences for disease.

In comparison to the shellfish industry, motivation to undertake biosecurity within the recreational boating sector was driven by economic opportunities. In some geographic areas there were funding opportunities for projects, which involved collaboration between local regulatory and non-regulatory organisations. Funding opportunities enabled stakeholders to produce plans, guidance, training materials and run workshops. Economic opportunities were extremely important for encouraging and motivating stakeholders to act on IAS in the marine environment and participants believed that these projects had knock on benefits which included community engagement and awareness raising.

However, whilst economic opportunities (such as funding) were an important factor for motivation, there were issues with the longevity and legacy of these plans once the funding had stopped. It was argued that motivation was only short-term as few projects continued

once funding had run out. There were only a few participants that continued to express interest in and 'champion' biosecurity after projects had ended. These individuals stressed how difficult it was to promote biosecurity on top of their existing work load and it would usually come low on their list of priorities. Therefore after the funding for projects ended, it was considered that the outputs of the projects in fact had no impact on the ground.

Unlike in the shellfish industry, biosecurity could not be enforced through economic consequences such as penalties, fines and bans within the recreational boating sector. Participants raised concerns with enforcing biosecurity at a marina/site as some boaters would be inclined to go elsewhere (to avoid additional effort). Therefore there were economic consequences to promoting and enforcing biosecurity as the business would lose money.

Participant 2: If you have a boat coming across to a marina, the guidance would say 'check out other boats coming into the arena [marina] and make sure they are not dirty'... Well, what do you tell them? You are not going to say go away because they want the money, and they are coming on holiday for a week, you are not going to say you don't want the fees.

Participants identified financial costs associated with IAS biosecurity implementation. These included the cost of enforcement (as this would require employing someone to check boats as they came in and out) and the cost of investing in infrastructure which was considered expensive, especially when this was not a legal requirement of a site, and also since boaters would be unlikely to use them.

Participant 1: We could possibly have byelaws to enforce it, but enforcement is going to cost money to implement as you have to have people and resources. But if it is going to be taken seriously, then I think you have to do that.

4.4.2.5 Conflicting advice

In both case studies there was confusion and conflicting voluntary or regulatory advice. Despite IAS biosecurity being a positive result from disease regulation in the shellfish industry, there was still some confusion around the reasons to do biosecurity for IAS prevention, especially with some IAS that are used for cultivation. Participants were concerned with who's responsibility it was to deal with accidental escape, in particular, some participants mentioned the accidental escape of the Pacific oyster.

In addition to this, there was some confusion and resentment among shellfish industry participants with recreational boating activities. Participants from the shellfish industry felt

that the boating sector was a high risk of spreading IAS and therefore felt that voluntary measures were not enough.

Participant 12: There is some conflict between aquaculture and recreational boating. Especially around best practice...Look at what we have to do and then look at what the recreational boaters don't have to do.

At the same time, there were issues around unclear and conflicting advice between regulatory and voluntary policy instruments within the recreational boating sector, which seemed to influence motivation to undertake biosecurity practice. For example, some participants were aware of the conflict between voluntary cleaning advice for recreational boating (promoting the *Check Clean Dry* campaign) which encourages individuals to remove visible fragments and the MSFD and Marine and Coastal Access Act which requires individuals have a licence to deposit any material or substance into the water:

Participant 2: I think it is still relevant, if we can make the cleaning a bit more clear. Because we can't say at the moment "clean your boat" because it is illegal, and we can't say "take you boat out and clean it" as that is just impractical.

4.4.2.6 Social norms

Due to the small size of the shellfish industry, behaviours had been developed and passed down and across the generations. This created a certain expectation among the industry that individuals would always undertake biosecurity measures as it was seen as normal behaviour.

In contrast, the large size and diffuse nature of the recreational boating sector meant that there was no expected standard of behaviour in relation to IAS biosecurity, with any practice usually the decision of the individual rather than the community. Participants from the recreational boating sector suggested that in order to motivate and change behaviours, policy would have to build social norms and nudge individuals to change behaviours.

Participant 3: It goes back to the psychology of nudging, so if you encourage the community to own the place then there is pride and it almost ensures a level of expectation, and then it is the norm.

When asked about barriers to undertaking biosecurity and future opportunities, participants from the recreational boating sector argued that individuals would be motivated to change behaviours if they saw others undertaking biosecurity practices.

Therefore participants would be likely to copy the behaviour of others and they would feel pressure to do so.

Participant 3: Because I think everyone is looking at each other and I think if someone else is doing it then they feel empowered, and they will do it too.

Finally, when discussing how to encourage behaviour change and the uptake of biosecurity practices, participants recognised that changing behaviours would take a long time, just as they have in other areas such as plastics and recycling.

4.5 Discussion

Our results suggest that motivation and intention to undertake biosecurity was influenced by the combination of policy instruments and other factors. Our work highlights the importance of these other factors, which are crucial for improving the effectiveness and acceptance of policy instruments in order to achieve the goals of policy. The marine environment is used by many different sectors and industries and therefore managing these stakeholders is key to reducing the consequences and impacts of IAS. However, we found that both the shellfish industry and recreational boating sector were subject to different drivers that influenced behaviour.

Firstly, the scale in which the stakeholders operated was an important factor for consideration in the analysis. Stakeholders from the shellfish industry were a mixture of regulators, governing bodies and business owners (farmers were the business owners). On the other hand, stakeholders from the recreational boating sector were mainly made of regulators, governing bodies and authorities; only one participant was a business owner. Therefore, interviewees from industry were speaking with different interests, where shellfish business owners were speaking in the context of their own business, compared to those from the recreational boating sector who focused on the context of the district or council.

The shellfish industry were motivated by existing regulatory instruments used for disease control (e.g. the Aquatic Animal Health Regulations 2009 and the Alien and Locally Absent Species in Aquaculture Regulations 2011). Therefore, biosecurity behaviour within the shellfish industry was as a result of the regulatory instruments that directly targeted disease control. Biosecurity practice for IAS was ultimately a co-benefit from these regulations rather than the voluntary guidelines/plans that were created specifically for IAS. In contrast, there were limited regulatory policy instruments used to influence behaviour in relation to biosecurity in the recreational boating industry which meant that the industry relied heavily on voluntary

instruments to encourage biosecurity behaviour change. These instruments were often regionally designed, where stakeholders had come together to produce local/regional biosecurity plans. Policy makers in the EU and UK have increasingly favoured the use of voluntary approaches, as a low cost, more flexible alternative to binding regulations which are often seen as a last resort (McCarthy and Morling 2015). However, there is little evidence to suggest that voluntary instruments can often be limited and ineffective and participation and behaviour change is low. Voluntary measures assume that increased awareness is followed by concern (i.e. change in attitude), which then increases motivation and adoption of pro-environmental behaviour (Gunningham and Sinclair 2002; Hulme et al. 2017). Floerl et al. (2016) found that the uptake of antifouling practice among boaters was poor, despite a heavy reliance on voluntary measures and awareness of the problem. This was because individuals were more likely to change their behaviour when the costs of the behaviours were borne more explicitly by those who practiced them and there was a perceived lack of transparency and accountability (Floerl et al. 2016). Similarly, our results suggest that whilst awareness of IAS and voluntary policy instruments was high within the recreational boating sector, awareness was not translated into positive attitudes towards the instruments nor changes in behaviour and participants acknowledged that these instruments had little motivational influence. This is important as it relates to Ajzen's Theory of Planned Behaviour argues that attitudes are an important factor for shaping an individual's behavioural intentions and behaviour (1991). Other elements from the Theory of Planned Behaviour were evidenced from both sectors, which were considered important for influencing behaviour e.g. social norms (see Appendix J). Participants also highlighted conflicts between existing law and the newly created voluntary instruments within the recreational boating sector. For example, there were issues between Water Directives and Regulations that prohibited the deposit of substances into the water, and voluntary guidance which encouraged the cleaning of boats in the water. Caution must be taken when integrating two or more behaviour change approaches (regulatory and voluntary instruments) to avoid these kinds of conflicts that can limit effectiveness (Taylor et al. 2013). The issue of mixed messages is recognised as a huge barrier to behaviour change (Floerl et al. 2016). This highlights the need for context specific advice for recreational boaters (as also discovered by Floerl et al (2016)) and further investment by government and stakeholders into the creation of biosecurity facilities in order to meet the goals of policy instruments. In addition to the conflict between regulatory and voluntary instruments, recreational boaters were also restricted by a lack of infrastructure available to them to implement the cleaning guidance advised in the voluntary instruments. Owens and Driffill (2008) argue that people can often be urged to do one thing but are constrained by practicality which can often lead to confusion, resentment or hostility. This is especially

important in the case of biosecurity for the recreational boating sector which relies on voluntary uptake; any confusion could have negative results. Voluntary approaches have a part to play in the environmental policy mix but cannot be assumed to change behaviour alone. Better design of voluntary instruments and the introduction of sanctions to penalise non performers, could see their success rates improve.

The lack of regulatory instruments and conflicting voluntary advice creates challenges for future management of recreational boating and pose major collective action problems within the marine environment. Collective action problems are when a group benefits from the action but no individual has sufficient incentive to act alone (Ostrom et al. 1999). Ostrom recognised the issue with governing common pool resources among a large number of users in a community and argues that when the group size is large, good-will alone will not be enough to get people to act for the common good (Ostrom 1990; Ostrom et al. 1999). Ostrom offered 8 principles for how commons issues can be governed; within larger communities monitoring and sanctions should be applied to ensure an increase in the importance of compliance (Ostrom et al. 1999). Where individuals monitor and sanction (i.e., reward or punish) behaviours, a virtuous cycle of trust-building can develop such that they become more willing to reciprocate others' actions as a means of enhancing their reputation for trustworthiness in the eyes of their peers (Marshall et al. 2016). In large groups however, self-monitoring is difficult; participants in our study argued that biosecurity in the recreational boating sector would be too difficult to monitor and enforce due to the size of the industry, this increases the need for regulation rather than voluntary agreements. Often a key element in promoting collective action in large-group settings is governance by a third party (Marshall et al. 2016). It may also be beneficial for the recreational boating sector to create an institution which can increase compliance among recreational boaters to reduce the risk of spread (Marshall et al. 2016).

Other factors such as trust (Graham 2014; Graham et al. 2019), developing a sense of community responsibility (Marshall et al. 2016), incentives (Ervin and Frisvold 2016) and social norms (Minato et al. 2010) are important to increase motivation. Subjective norms are also important for increasing an individual's behavioural intention and likelihood to change their behaviour. In particular, the shellfish industry relied on social norms as the practice was strongly linked to values, traditions and values which are important cultural components of social norms (Rivis and Sheeran 2003). Our results highlight the importance of incentives to motivate behaviour which inevitably drives behaviour change. Not only was there a clear financial incentive to undertake biosecurity for disease control within the shellfish industry, there was also a financial incentive for the shellfish industry to undertake

biosecurity for IAS, as it was understood that biosecurity would reduce the risk of production losses and monetary consequences of poorly managed threats to food production from IAS. Financial incentives may be in the form of either rewards or penalties; here financial incentives were in the form of penalties. The use of financial incentives and disincentives have proven useful in other industries to drive pro-environmental behaviour and compliance; for example Mankad (2016) found that agricultural farmers were motivated to undertake biosecurity due to financial penalties similar to those found in our study (e.g. production losses and monetary consequences) as well as non-financial consequences such as perceptions and approval of others. For economic activities (i.e. aquaculture) financial incentives are critical for driving behaviour because they ultimately affect the business.

In contrast, there were no financial incentives or penalties for recreational boaters to undertake biosecurity. There was a financial burden to many individuals as there were economic consequences of enforcing biosecurity as boaters may be more inclined to go somewhere else out of ease, therefore marinas would lose money by promoting biosecurity. Policy makers should consider incentivising biosecurity behaviour with a reward scheme as opposed to enforcement and penalties which could potentially economically impact marinas. The underlying assumption for incentivising behaviour is that people are most likely to respond if there is something to be gained (or a loss to avoid). In other areas of IAS management, financial incentives have been given to landowners to control IAS on their land; providing financial incentives was the main way that government tried to provide landowners with support to control serrated tussock in a qualitative study by Graham (2013). Incentives and disincentives are needed to increase ownership and accountability which in turn should increase compliance; for example Floerl et al. (2016) suggest that a combination of the 'carrot and stick' approach, command and control systems and social marketing approach (to elicit voluntary action) should be an effective option for increasing the adoption of behaviours to reduce the spread of IAS among recreational vessels.

In addition to financial incentives, social incentives (individuals' perceptions of others behaviours) can also be used to foster socially desirable behaviours and increase compliance and willingness to undertake biosecurity among recreational boaters. In the field of recycling, social incentives play an important role in explaining the extent to which individuals choose to undertake pro-environmental behaviours, as individuals still choose to recycle even in the absence of any financial incentive. Barr et al. (2001) concluded that as recycling is a visible activity then social norms are a key determinant; seeing people put out recycling can have a positive effect in encouraging others to recycle. Bedford et al. (2010) argue that recycling has

now become a 'pro-social norm' such that people can be stigmatised as selfish and anti-social for not recycling. Biosecurity is also a visible activity, therefore there is opportunity and potential for social norms to play an important part in behaviour change. Nyborg et al (2016) argue that social norms spread through social networks when a community is connected and therefore individuals see and copy behaviour to fit in. Social incentives rely on social networks which are extremely important as groups are influenced by social preferences and the strength of identity, social norms that exist within the community (Prinbeck et al. 2011). We propose that it is likely that social networks were hugely effective at reinforcing social norms and existing behaviours within the shellfish industry because of the small size of the industry and connectivity between businesses which facilitated cooperation among individuals. Therefore, a key challenge for encouraging biosecurity behaviours in the recreational boating sector is to identify and tap into existing social networks that may be able to spread knowledge about biosecurity, and to stimulate new networks where links are undeveloped (e.g. between different scales or between social groups that do not typically interact with one another) (Stringer et al. 2006). However due to the large size and disparate nature of the recreational boating sector, social networks are not necessarily the best means of communicating social incentives. Instead, the recreational boating sector should increase the visibility of biosecurity behaviour by implementing cleaning stations in popular areas so they are visible to boaters and encourage/nudge boaters to use them. Nyborg et al (2016) argue that often when a behaviour is easily observed and simple to follow, willingness to cooperate through moral responsibility increases. Nudges work by making the desired behaviour easier and simpler and more engaging (Thaler and Sunstein 2008). For example, nudges (installing waste bins) decreased littering by making the behaviour (disposing of rubbish in the bins) easier (Thaler and Sunstein 2008). Whilst there is an initial cost, these type of nudges are attractive because they are cost-effective and allow the individual to change behaviours avoiding regulations and economic penalties that can influence attitudes (Jennings et al. 2018). Therefore, nudges that focus on implementing wash down stations will target intuitive thinking without restricting choices and therefore encourage pro-environmental behaviour. If the behaviour is visible and easy to copy, the faster and more widely the behaviour can spread (Quested et al. 2013). As with any new technology, idea or approach, getting people to adopt biosecurity measures involves a gradual process of behaviour change that may take time to be adopted as a social norm. Policy instruments for the recreational boating sector should be designed to foster the creation of new social norms and utilise incentives and nudging to improve voluntary compliance.

4.6 Conclusion

Marine IAS management requires change in human behaviour to prevent unintentional introduction and spread of IAS in the environment. The findings from this study can contribute to future research about the human dimensions of IAS and also help inform those wanting to create more effective IAS policy within the marine environment. Our research confirms that awareness campaigns and instruments that rely on voluntary compliance are unlikely to be effective for the recreational boating sector, as knowledge alone does not necessarily translate into positive environmental behaviour for most people. We recommend that where there is conflict or lack of motivation, social incentives (and nudges) should be used to encourage socially desirable behaviours and increase compliance and willingness to undertake biosecurity within the recreational boating sector. Insights from the social and behavioural sciences are critical for scientists and practitioners to understand behaviour change in relation to biosecurity and to achieve the goals of international policy.

4.7 References

- Abrahamse W, Steg L. 2013. Social influence approaches to encourage resource conservation: A meta-analysis. *Glob Environ Chang* 23:1773–1785. doi: 10.1016/j.gloenvcha.2013.07.029
- Acosta H, Forrest BM. 2009. The spread of marine non-indigenous species via recreational boating: A conceptual model for risk assessment based on fault tree analysis. *Ecol Modell* 220:1586–1598. doi: 10.1016/j.ecolmodel.2009.03.026
- Ajzen I. 1991. The theory of planned behaviour. *Organ Behav Hum Decis Process* 50:179–211. doi: 10.1016/0749-5978(91)90020-T
- Barr S, Gilg AW, Ford NJ. 2001. Differences Between Household Waste Reduction, Reuse and Recycling Behaviour : A Study of Reported Behaviours, Intentions and Explanatory Variables. *Environ Waste Manag* 4:69–82
- Bedford T, Collingwood P, Darnton A, et al. 2010. Motivations for Pro-environmental Behaviour: A report to the Department for Environment, Food and Rural Affairs. London
- Bhattacharjee A. 2012. *Social science research: Principles, methods, and practices*, 2nd edn. University of South Florida, Florida

- Cialdini RB, Reno RR, Kallgren C. 1990. A focus theory of normative conduct: Recycling the concept of norms to reduce littering in public places. *J Pers Soc Psychol* 58:1015–1026. doi: 10.1037/0022-3514.58.6.1015
- Colvin RM, Witt GB, Lacey J. 2016. Approaches to identifying stakeholders in environmental management : Insights from practitioners to go beyond the ‘usual suspects .’ *Land use policy* 52:266–276. doi: 10.1016/j.landusepol.2015.12.032
- Cottier-Cook EJ, Minchin D, Giesler RJ, et al. 2019. Biosecurity implications of the highly invasive carpet sea-squirt *Didemnum vexillum* Kott, 2002 for a protected area of global significance. *Manag Biol Invasions* 10:311–323
- Critchley AT, Farnham WF, Morrell SL. 1986. An Account of the Attempted Control of an Introduced Marine Alga, *Sargassum muticum*, in Southern England. *Biol Conserv* 35:313–332. doi: 10.1016/0006-3207(86)90092-3
- Cronin K, Kaplan H, Gaertner M, et al. 2017. Aliens in the nursery: assessing the attitudes of nursery managers to invasive species regulations. *Biol Invasions* 19:925–937. doi: 10.1007/s10530-016-1363-3
- Delabbio JL, Johnson GR, Murphy BR, et al. 2005. Fish disease and biosecurity: Attitudes, beliefs, and perceptions of managers and owners of commercial finfish recirculating facilities in the United States and Canada. *J Aquat Anim Health* 17:153–159. doi: 10.1577/H04-005.1
- Eiswerth ME, Yen ST, van Kooten GC. 2011. Factors determining awareness and knowledge of aquatic invasive species. *Ecol Econ* 70:1672–1679. doi: 10.1016/j.ecolecon.2011.04.012
- Ellis T, Gardiner R, Gubbins M, et al. 2015. *Aquaculture statistics for the UK, with a focus on England and Wales: 2012*. Weymouth
- Ervin DE, Frisvold GB. 2016. Community-Based Approaches to Herbicide-Resistant Weed Management: Lessons from Science and Practice. *Weed Sci* 64:609–626. doi: 10.1614/ws-d-15-00122.1
- FAO. 2019. Aquaculture. <http://www.fao.org/3/x6941e/x6941e04.htm>. Accessed 27 Apr 2019
- Ferrario J, Marchini A, Borrelli P, et al. 2016. A fuzzy ‘boater’ model to detect fouling and spreading risk of non-indigenous species by recreational boats. *J Environ Manage* 182:198–207. doi: 10.1016/j.jenvman.2016.07.029

- Floerl O, Inglis GJ, Diettrich J. 2016. Incorporating human behaviour into the risk–release relationship for invasion vectors: why targeting only the worst offenders can fail to reduce spread. *J Appl Ecol* 53:742–750. doi: 10.1111/1365-2664.12609
- Glasby TM, Connell SD, Holloway MG, Hewitt CL. 2007. Nonindigenous biota on artificial structures: Could habitat creation facilitate biological invasions? *Mar Biol* 151:887–895. doi: 10.1007/s00227-006-0552-5
- Glaser BG. 1965. The Constant Comparative Method of Qualitative Analysis. *Soc Probl* 12:436–445. doi: 10.2307/798843
- Graham S. 2013. Three cooperative pathways to solving a collective weed management problem. *Australas J Environ Manag* 20:116–129. doi: 10.1080/14486563.2013.774681
- Graham S. 2014. A new perspective on the trust power nexus from rural Australia. *J Rural Stud* 36:87–98. doi: 10.1016/j.jrurstud.2014.06.010
- Graham S, Metcalf AL, Lubeck A, et al. 2019. Opportunities for better use of collective action theory in research and governance for invasive species management. *Conserv Biol* 33:275–287. doi: 10.1111/cobi.13266
- Griffith K, Mowat S, Holt RHF, et al. 2009. First records in Great Britain of the invasive colonial ascidian *Didemnum vexillum* Kott, 2002. *Aquat Invasions* 4:581–590. doi: 10.3391/ai.2009.4.4.3
- Guest G, Namey EE, Mitchell ML. 2012. *Collecting Qualitative Data: A Field Manual for Applied Research*. Sage Publications, London, UK
- Gunningham N, Sinclair D. 2002. *Voluntary Approaches to Environmental Protection : Lessons from the Mining and Forestry Sectors*. Paris
- Herbert RJH, Humphreys J, Davies CJ, et al. 2016. Ecological impacts of non-native Pacific oysters (*Crassostrea gigas*) and management measures for protected areas in Europe. *Biodivers Conserv* 25:2835–2865. doi: 10.1007/s10531-016-1209-4
- Howard-Payne L. 2016. Glaser or Strauss? Considerations for selecting a grounded theory study. 46:50–62. doi: 10.1177/0081246315593071
- Hulme PE, Brundu G, Carboni M, et al. 2017. Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *J Appl Ecol* 55:92–98. doi: 10.1111/1365-2664.12953

- Humair F, Kueffer C, Siegrist M. 2014. Are non-native plants perceived to be more risky? Factors influencing horticulturists' risk perceptions of ornamental plant species. *PLoS One* 9:e102121. doi: 10.1371/journal.pone.0102121
- Humphreys J, Harris MRC, Herbert RJH, et al. 2015. Introduction, dispersal and naturalization of the Manila clam *Ruditapes philippinarum* in British estuaries, 1980–2010. *J Mar Biol Assoc United Kingdom* 95:1163–1172. doi: 10.1017/S0025315415000132
- Humphreys J, Herbert RJH, Roberts C, Fletcher S. 2014. A reappraisal of the history and economics of the Pacific oyster in Britain. *Aquaculture* 428–429:117–124. doi: 10.1016/j.aquaculture.2014.02.034
- Hungerford HR, Volk TL. 1990. Changing Learner Behaviour through Environmental Education. *J Environ Educ* 21:8–21. doi: 10.1080/00958964.1990.10753743
- Jennings S, Sibly H, Yamazaki S, et al. 2018. When push comes to shove in recreational fishing compliance, think 'nudge.' *Mar Policy* 95:256–266. doi: 10.1016/j.marpol.2018.05.026
- Katsanevakis S, Zenetos A, Belchior C, Cardoso AC. 2013. Invading European Seas: Assessing pathways of introduction of marine aliens. *Ocean Coast Manag* 76:64–74. doi: 10.1016/j.ocecoaman.2013.02.024
- Kelly J, Tosh D, Dale K, Jackson A. 2013. The economic cost of invasive and non-native species in Ireland and Northern Ireland. A Rep Prep North Irel Environ Agency Natl Park Wildl Serv as part Invasive Species Irel 1–95
- Kettunen M, Genovesi P, Gollasch S, et al. 2009. Technical support to EU strategy on invasive alien species (IAS) - Assessment of the impacts of IAS in Europe and the EU (final module report for the European Commission). Brussels, Belgium
- Kollmuss A, Agyeman J. 2002. Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behaviour? *Environ Educ Res* 8:239–260. doi: 10.1071/WR14122
- Laing I, Lees DN, Page DJ, Henshilwood K. 2004. Research on shellfish cultivation. *Sci Ser Tech Rep* 68
- Macleod A, Payne RD, Cook EJ. 2014. Marine Biosecurity Planning: Guidance for producing site and operation-based plans for preventing the introduction of non-native species

- Mankad A. 2016. Psychological influences on biosecurity control and farmer decision-making. A review. *Agron Sustain Dev* 36:1–14. doi: 10.1007/s13593-016-0375-9
- Marshall GR, Coleman MJ, Sindel BM, et al. 2016. Collective action in invasive species control, and prospects for community-based governance: The case of serrated tussock (*Nassella trichotoma*) in New South Wales, Australia. *Land use policy* 56:100–111. doi: 10.1016/j.landusepol.2016.04.028
- McCarthy D, Morling P. 2015. *Using Regulation as a Last Resort: Assessing the Performance of Voluntary Approaches*. Bedfordshire: UK
- McKenzie-Mohr D, Schultz PW. 2014. Choosing effective behaviour change tools. *Soc Mar Q* 20:35–46. doi: 10.1177/1524500413519257
- Michie S, Stralen MM Van, West R. 2011. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement Sci* 6:42. doi: 10.1186/1748-5908-6-42
- Michie S, West R. 2013. Behaviour change theory and evidence: A presentation to Government. *Health Psychol Rev* 7:1–22. doi: 10.1080/17437199.2011.649445
- Minato W, Curtis A, Allan C. 2010. Social norms and natural resource management in a changing rural community. *J Environ Policy Plan* 12:381–403. doi: 10.1080/1523908X.2010.531084
- Minchin D, Cook EJ, Clark PF. 2013a. Alien species in British brackish and marine waters. *Aquat Invasions* 8:3–19. doi: 10.3391/ai.2013.8.1.02
- Minchin D, Nunn JD, Agency NIE. 2013b. Rapid assessment of marinas for invasive alien species in Northern Ireland. *Res Dev Ser* 116
- Morgan A. 2011. *Investigating Our Experience in the World: A Primer on Qualitative Inquiry*. University of Tennessee Press, Tennessee
- Nyborg K, Anderies JM, Dannenberg A, et al. 2016. Social norms as solutions. *Science* (80) 354:42–43
- Ostrom E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge

- Ostrom E, Burger J, Field CB, et al. 1999. Revisiting the Commons: Local Lessons, Global Challenges. *Science* (80) 284:278–282. doi: 10.1126/science.284.5412.278
- Owens S, Driffill L. 2008. How to change attitudes and behaviours in the context of energy. *Energy Policy* 36:4412–4418. doi: 10.1016/j.enpol.2008.09.031
- Polonsky MJ, Binney W, Hall J. 2004. Developing Better Public Policy to Motivate Responsible Environmental Behaviour—An Examination of Managers’ Attitudes and Perceptions Towards Controlling Introduced Species. *J Nonprofit Public Sect Mark* 12:49–67. doi: 10.1300/J054v12n01
- Prinbeck G, Lach D, Chan S. 2011. Exploring stakeholders’ attitudes and beliefs regarding behaviours that prevent the spread of invasive species. *Environ Educ Res* 17:341–352. doi: 10.1080/13504622.2010.542451
- Quested TE, Marsh E, Stunell D, Parry AD. 2013. Spaghetti soup: The complex world of food waste behaviours. *Resour Conserv Recycl* 79:43–51. doi: 10.1016/j.resconrec.2013.04.011
- Reed MS, Curzon R. 2015. Stakeholder mapping for the governance of biosecurity: a literature review. *J Integr Environ Sci* 12:15–38. doi: 10.1080/1943815X.2014.975723
- Reed MS, Graves A, Dandy N, et al. 2009. Who’s in and why? A typology of stakeholder analysis methods for natural resource management. *J Environ Manage* 90:1933–1949. doi: 10.1016/j.jenvman.2009.01.001
- Roche RC, Monnington JM, Newstead RG, et al. 2015. Recreational vessels as a vector for marine non-natives: developing biosecurity measures and managing risk through an in-water encapsulation system. *Hydrobiologia* 750:187–199. doi: 10.1007/s10750-014-2131-y
- Rothlisberger JD, Chadderton WL, McNulty J, Lodge DM. 2010. Aquatic Invasive Species Transport via Trailered Boats: What is Being Moved, Who is Moving it, and What Can Be Done. *Fisheries* 35:121–132. doi: 10.1577/1548-8446-35.3.121
- Roy HE, Bacon J, Beckmann B, et al. 2012. Non-Native Species in Great Britain: establishment, detection and reporting to inform effective decision making. 1–110
- RYA. 2017. Pleasure Craft Regulations. <http://www.rya.org.uk/knowledge-advice/regulations/pleasure-craft/Pages/hub.aspx>. Accessed 4 Jan 2018
- RYA. 2014. Economic contribution of the recreational boater. Southampton, UK

- Ryan GW, Bernard HR. 2003. Techniques to Identify Themes. *Field methods* 15:85–109. doi: 10.1177/1525822X02239569
- SAGB. 2019. Shellfish Associated of Great Britain.
<http://www.shellfish.org.uk/about.html#Whatwedo>. Accessed 2 Apr 2019
- Schlag AK. 2010. Aquaculture: an emerging issue for public concern. *J Risk Res* 13:829–844. doi: 10.1080/13669871003660742
- Schultz PW. 2002. Chapter: 4. Knowledge, Information, and Household Recycling: Examining the Knowledge-Deficit Model of Behaviour Change. In: *New Tools for Environmental Protection: Education, Information, and Voluntary Measures*. pp 67–82
- Seekamp E, McCreary A, Mayer J, et al. 2016. Exploring the efficacy of an aquatic invasive species prevention campaign among water recreationists. *Biol Invasions* 18:1745–1758. doi: 10.1007/s10530-016-1117-2
- Simberloff D, Martin J-L, Genovesi P, et al. 2013. Impacts of biological invasions: What's what and the way forward. *Trends Ecol Evol* 28:58–66. doi: 10.1016/j.tree.2012.07.013
- Strauss A, Corbin J. 1990. *Basics of qualitative research: Grounded theory procedures and techniques*. Sage Publications, Newbury Park
- Taylor CM, Pollard SJT, Angus AJ, Rocks SA. 2013. Better by design: Rethinking interventions for better environmental regulation. *Sci Total Environ* 447:488–499. doi: 10.1016/j.scitotenv.2012.12.073
- Thaler R, Sunstein C. 2008. *Nudge: improving decisions about health, wealth, and happiness*. Yale University Press, New Haven, CT
- Tidbury HJ, Taylor NGH, Copp GH, et al. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biol Invasions* 18:3277–3292. doi: 10.1007/s10530-016-1219-x
- Vander Zanden MJ, Olden JD. 2008. A management framework for preventing the secondary spread of aquatic invasive species. *Can J Fish and Aquat Sci* 65:1512–1522. doi: 10.1139/F08-099

Ventura L De, Weissert N, Tobias R, et al. 2016. Overland transport of recreational boats as a spreading vector of zebra mussel *Dreissena polymorpha*. *Biol Invasions* 18:1451–1466. doi: 10.1007/s10530-016-1094-5

Wald DM, Nelson KA, Gawel AM, Rogers HS. 2019. The role of trust in public attitudes toward invasive species management on Guam: A case study. *J Environ Manage* 229:133–144. doi: 10.1016/j.jenvman.2018.06.047

Williams F, Eschen R, Harris A, et al. 2010. *The Economic Cost of Invasive Non-Native Species on Great Britain*. Oxford, UK

Williamson M, Fitter A. 1996. The varying success of invaders. *Ecology* 77:1661–1666. doi: 10.2307/2265769

Chapter 5: The practical application of hot water to reduce the introduction and spread of aquatic invasive alien species

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5.1 Abstract

Methods to prevent the introduction and spread of Invasive Alien Species (IAS) are key to reducing the economic, environmental and social impacts of IAS. IAS propagules can be moved around accidentally on clothing and equipment used in agriculture, transport, trade and recreation. Campaigns to slow the spread of aquatic IAS encourage water users to check, clean and dry their equipment and clothes, using hot water in the cleaning process where feasible. The UK *Check Clean Dry* biosecurity campaign recommends immersion in hot water (45°C) for 15 minutes. However, implementation time may be a barrier to biosecurity adoption. Here we refine the advice given and test the efficacy in actual conditions, with a view to reduce the recommended time to clean equipment while still preventing spread. The effectiveness was tested of a range of temperature (40, 45, 50, 55 and 60°C) and time (10 seconds, 1, 5, 10, 15 minutes) treatments in killing IAS propagules of two invasive aquatic animal species (*Dreissena polymorpha*, *Dikerogammarus villosus*) and two invasive aquatic plant species (*Myriophyllum aquaticum*, *Crassula helmsii*), which are of global/national importance. For both invasive animal species, 100% mortality was achieved at all temperature and time treatments. However, plant mortality was affected by both temperature and time, with higher mortality resulting from higher temperatures and exposure times. Immersion for the recommended 15 mins at 45°C caused complete mortality of *Crassula helmsii*, but only 40% mortality of *Myriophyllum aquaticum*. Immersion in water at 50°C or above led to 100% mortality for *Crassula helmsii* and 90% mortality for *Myriophyllum aquaticum* at shorter treatment durations of 5 or 10 mins. In addition, immersion in water at 60°C caused 100% mortality after only 1 minute exposure. To ensure adoption and application of biosecurity, guidance should be simple, consistent and safe. For practical application in field we recommend, where feasible, immersion of equipment in water at 50°C for a minimum of 5 minutes to achieve high mortality of IAS propagules.

5.2 Introduction

The rate of biological invasions is increasing as species are being moved (intentionally or unintentionally) through human activity outside their natural distribution into novel terrestrial, marine and freshwater environments (Lockwood et al. 2005; Zieritz et al. 2016). Non-native species that have the capacity to spread and have negative ecological, economic or social impacts in their novel range are termed Invasive Alien Species (IAS). Freshwater ecosystems are disproportionately affected by IAS (Dudgeon et al. 2006; Ricciardi and Maclsaac 2010) due to high anthropogenic activity, including trade and transport, recreation and environmental management. For example, recent research has indicated that almost 40% of aquatic species introductions into Europe are a result of aquaculture, boating, fishing and leisure activities (Gallardo and Aldridge 2013). IAS in the freshwater environment can be dispersed on footwear and motor vehicles (Waterkeyn et al. 2010) and on equipment such as netting and wetsuits (Anderson et al. 2015). Once introduced and established, IAS can be extremely difficult and expensive to eradicate, particularly within aquatic environments (Barbour et al. 2013; Tidbury et al. 2016). After establishment has occurred, preventing secondary spread becomes paramount for slowing the spread of IAS (Vander Zanden and Olden 2008; Beyer et al. 2011).

Methods to prevent the introduction and spread of IAS are central to the Convention on Biological Diversity (CBD), to EU Regulation 1143/2014 on the Prevention and Management of Invasive Alien Species, and to the Great Britain invasive non-native species (GBNNS) Strategy for Great Britain (Perrings et al. 2009; Dunn and Hatcher 2015). The 20th International Conference on Aquatic Invasive Species, Florida, USA, 2017, widely recognised that prevention was one of the most cost effective methods to prevent and reduce the risk of new introductions, and focuses on engaging the public to encourage prevention of new introductions (<https://www.icaiss.org/>). Biosecurity measures cover all activities aimed at preventing the introduction and/or spread of IAS (Caffrey et al. 2014). A key aspect of biosecurity, are practices that reduce the risk of introduction and/or spread of IAS on fomites (e.g. clothing or equipment). As only a few individuals or plant fragments may be required to establish a new population, it is critical to establish simple, cost effective biosecurity messages and methods particularly when focused on engaging the public to encourage prevention of new introductions. The advice for biosecurity is adopted globally, for example in the United States the *Clean Drain Dry* campaign is a call to action that empowers recreational users of aquatic resources (<http://stopaquaticitchhikers.org/>). In addition to this, the New Zealand *Check Clean Dry* campaign, launched in 2004 has been effective in slowing the spread of an invasive diatom *Didymosphenia geminata* (Lyngbye) M. Schmidt, 1899 (Branson 2006). A similar campaign was launched by the UK Department for Environment, Food and Rural Affairs (Defra) in 2010 in

response to the first reports of the invasive alien killer shrimp *Dikerogammarus villosus* (Sowinsky, 1894). The UK *Check Clean Dry* campaign is aimed at recreational and other water users and promotes biosecurity best practice to reduce the risk of accidental introduction and spread of aquatic IAS. The campaign encourages people to check, clean and dry all equipment and clothing thoroughly to kill or remove any organisms that have the potential to survive while attached to equipment and be transported to a new location. The 'Clean' recommendations advised by the GBNNS Secretariat involves washing all equipment, footwear and clothes thoroughly.

The use of hot water has been identified as a technique globally to support the 'Clean' process within the *Check, Clean, Dry* campaigns (Beyer et al. 2011; Stebbing et al. 2011; Anderson et al. 2015) including the *Check Clean Dry* in the UK

(<http://www.nonnativespecies.org//checkcleandry/index.cfm>); and the United States, *Clean Drain Dry* (www.stopaquaticinvasives.org). Previous studies have found that aquatic plant fragments and animals are able to survive for at least 16 days in damp conditions, and that, although drying killed IAS propagules, several days drying time were required to reach high mortality (Anderson et al. 2015). The effectiveness and speed of mortality was increased by using hot water to clean equipment and clothing: Anderson et al. (2015) found that immersion for 15 minutes in 45°C water caused 99% mortality among seven high impact UK aquatic IAS. Anderson et al. (2015) tested mortality using controlled water baths in laboratory conditions. However, in domestic/field settings, biosecurity is likely to be carried out using buckets in which hot water will cool naturally during treatment. Furthermore, through interviews with stakeholders from a range of environmental organisations (including business, leisure, conservation, education and public organisations), it has been argued that 15 minutes may be too long to ask people to wait for their equipment to soak and may be difficult to incorporate into their working practices (Sutcliffe et al. 2017). Reducing the time taken to undertake biosecurity may increase the adoption of good biosecurity practices.

This study aimed to reduce the time taken to perform key biosecurity activities (cleaning of equipment using hot water) and test the effectiveness of those activities. The objectives were: (a) to determine whether a shorter immersion time can result in high mortality of IAS propagules at the recommended 45°C and (b) to investigate whether higher temperatures can be combined with shorter treatment times to induce high mortality of IAS propagules. Experiments were carried out using hot water in domestic buckets as is likely to occur in field or domestic settings, rather than laboratory water baths.

5.3 Materials and Methods

Experiments were conducted between 2016 and 2017 and focused on four representative species. Zebra mussels *Dreissena polymorpha* are of global concern, potentially being transported through shipping from the Ponto Caspian region to Western Europe and North America. Killer shrimp (*Dikerogammarus villosus*), New Zealand pigmyweed, *Crassula helmsii*, and Parrot's feather *Myriophyllum aquaticum* are of EU concern (<http://www.europe-aliens.org/speciesTheWorst>). IAS were hand collected from various sites within the UK. *Dreissena polymorpha* were collected from Grafham Water, Peterborough (52.303°N, -0.321°E) in September 2016. *Dikerogammarus villosus* were collected from the same site in January 2017. In March 2016 emergent *Crassula helmsii* was collected from Potteric Carr Nature Reserve, Doncaster (53.499°N, -1.114°E) and in June 2016 *Myriophyllum aquaticum* was collected from Stocks Moor Common, Wakefield (53.631°N, -1.588°E). Plants and animals were brought back after collection immediately and stored in separate tanks of aerated freshwater (tap water that had been allowed to stand for >24h before use at 14°C) for 48 hours before the experiment to allow them to acclimatise prior to experimentation. Tanks were stored within a constant temperature room (14 ± 1°C light: dark cycle 12:12h). During field collection, laboratory storage and experimentation, good biosecurity was observed at all times.

The health status of the animals and plant fragments was checked before use in experiments to ensure that only healthy individuals were used, and again at the end of the experiment to measure mortality after treatment. To determine whether the plants were healthy before use in the experiments, a FluorPen (FP 100, Photon Systems Instruments) was used. The FluorPen recorded two parameters: the equivalent variable fluorescence and the maximal fluorescence (Fv:Fm) which is a measurement of the chlorophyll fluorescence, commonly used as an indicator of plant stress (Hetherington and Smillie 1982; Willits and Peet 2001). Plants with scores of 0.7 or above were considered healthy and were to be used for the experiment (Willits and Peet 2001). Healthy *Dikerogammarus villosus* and *Dreissena polymorpha* were identified as those that responded to mechanical stimuli (swimming or siphoning) which involved gently touching animals with a probe near their siphons to see if their shells closed. At the end of the experiment, plants with Fv:Fm values of 0.3 or below were considered to be dead (Dan et al. 2000). A previous study using Fv:Fm to estimate plant mortality found that those plants recorded as dead 24h after hot water immersion showed no evidence of recovery after a further 16 days (Anderson et al. 2015). Hence, although we cannot discount the possibility of some plant recovery this method provides a simple means to compare mortality. *Dikerogammarus villosus* were considered dead if they failed to respond to stimuli

or had decomposed, and *Dreissena polymorpha* were assumed dead if their shells gaped and they did not respond to stimuli (Beyer et al. 2011).

For experimentation, plants fragments were taken and cut into fragments of 60mm making sure the reproductive part of the plant was not removed. *Dreissena polymorpha* and *Dikerogammarus villosus* were randomly selected from the stock tanks (Beyer et al. 2011). *Dreissena polymorpha* ranged in total length from 11mm to 33mm (median 23mm), and *Dikerogammarus villosus* ranged in total length from 3mm to 13mm (median 8mm). Individual bags made from nylon mesh at 100mm² contained ten replicates of each species and sealed with staples. The netting aimed to replicate anglers' keep nets or sampling nets on which fragments or animals could be found/trapped. The bags were then submerged in a flexi bucket containing 16 litres of freshwater (tap water that had been allowed to stand for >24h before use) at $14 \pm 1^\circ\text{C}$ for an hour before the experiment in order to simulate an angling trip or other water activities.

Nets containing the animals/plant fragments were subject to one of 5 different starting immersion temperatures of tap water to account for both domestic and commercial hot water temperatures (40, 45, 50, 55, 60°C) and one of 5 treatment times (15, 10, 5, 1 minute, 10 seconds). Initially we conducted 10 replicates per treatment. As mortality was 100% across all treatments for the two animal species, but <100% for the plants, we conducted a further 10 replicates for each plant treatment. As the *Check Clean Dry* campaign is aimed at recreational users, we did not use a water bath but used large (19 litre) buckets to simulate domestic or field depot setting. For example, water temperature decreased from 60°C to 56.5°C and 40°C to 38.7°C in 15 minutes. Exposure times ranged from 15 minutes down to 10 seconds, in order to cover all realistic times that might be applied in the field (Stebbing et al. 2011; Anderson et al. 2015). Once exposure time was completed bags were removed and placed back into freshwater at $14 \pm 1^\circ\text{C}$ for 15 minutes. Plants and animals were returned to a constant temperature room in freshwater ($14 \pm 1^\circ\text{C}$ light: dark cycle 12: 12 h) for 24 hours before being recorded as dead or alive.

An additional experiment was undertaken to confirm that propagule death was a result of the immersion in hot water, and not a result of the rapid return to water at 14°C post hot water treatment. Propagules were exposed to hot water (10 replicates of each species at 40°C 10 of each species at 50°C for 10 mins) as above. Post-immersion, the water was then allowed to cool naturally to 14°C with mortality recorded at 24h as above.

5.3.1 Data analysis

All statistical analyses were undertaken in R version 3.3.2 and RStudio version 1.0.136 (R Core Team 2016; RStudio Team 2016). To test the effectiveness of treatment (temperature and time), generalised linear models were initially used with binomial errors to account for the binary nature of the survival response variable. However, standard application of logistic regression produced perfect separation in some cases. Therefore, we employed Firth's bias-reduced penalised-likelihood logistic regression (Firth 1993) using the `logistf` package (Heinze and Ploner 2016) in R. Traditional posthoc tests are not available for penalised-likelihood logistic regression, and so differences between treatment levels were evaluated using tests of proportions, corrected for multiple tests using false discovery rates in R. The `Exact-CI` function within the `PropCIs` package (Scherer 2018) was used to compute a 95% confidence interval for each of the proportions being calculated for each parameter estimates.

5.4 Results

There was 100% mortality of both *Dikerogammarus villosus* and *Dreissena polymorpha* animal species for all time and temperature treatments (Figure 5.1). In contrast, mortality in the two plant species was significantly affected by temperature and by treatment duration (Figure 5.1, Table 5.1a and 5.1b).

Table 5.1a. Penalised likelihood logistic regression for the effect of temperature and immersion duration on mortality of *Crassula helmsii*

	Coefficient	χ^2	<i>P</i>
(Intercept)	-14.683	53.380	<0.001
Temperature	0.299	49.872	<0.001
Time	-2.754	27.729	<0.001
Temperature x Time	0.068	33.035	<0.001

Table 5.1b. Penalised likelihood logistic regression for the effect of temperature and immersion duration on *Myriophyllum aquaticum*

	Coefficient	χ^2	<i>P</i>
(Intercept)	-10.43	61.701	<0.001
Temperature	0.209	59.114	<0.001
Time	-1.074	13.119	<0.001
Temperature x Time	0.028	18.336	<0.001

There was 100% mortality for both animal species and for *Crassula helmsii*. However, mortality was only 40% in *Myriophyllum aquaticum*. In contrast, a higher starting temperature of 50°C or above for the recommended 15 minutes caused >90% mortality for both plant species (Figure 5.1).

While the time spent immersed at 45°C had a significant effect on survival in *Crassula helmsii* ($\chi^2_1 = 54.519$ $P < 0.001$) and *Myriophyllum aquaticum* ($\chi^2_1 = 6.803$, $P = 0.009$), there was a significant reduction in mortality of *Crassula helmsii* from 100% to 50% when treatment duration at 45°C was reduced from 15 minutes to 10 minutes (Figure 5.1; $\chi^2_1 = 7.135$, $P = 0.007$). Mortality was only 40% for *Myriophyllum aquaticum* with a treatment duration of 15 mins, and as shorter treatment times were less effective for both plant species (Figure 5.1, Table 5.1).

We therefore went on to explore the effectiveness of higher temperature treatments at time durations shorter than 15 minutes in killing IAS propagules. Immersion for as little as 10 seconds caused 100% mortality at all temperature treatments for *Dikerogammarus villosus* and *Dreissena polymorpha* (Figure 5.1). However, plant mortality was affected by both temperature and duration of treatment with higher temperatures and longer durations leading to greater mortality (Figure 5.1). Immersion in water at 50°C and 55°C for 5 minutes caused high mortality (90-100%) for all plant and animal species and immersion at 60°C for a shorter time of 10 secs caused 100% mortality. Mortality was also high (100% for all species) when propagules were immersed for 10 mins at 40°C and 50°C and then allowed to gradually return to 14°C.

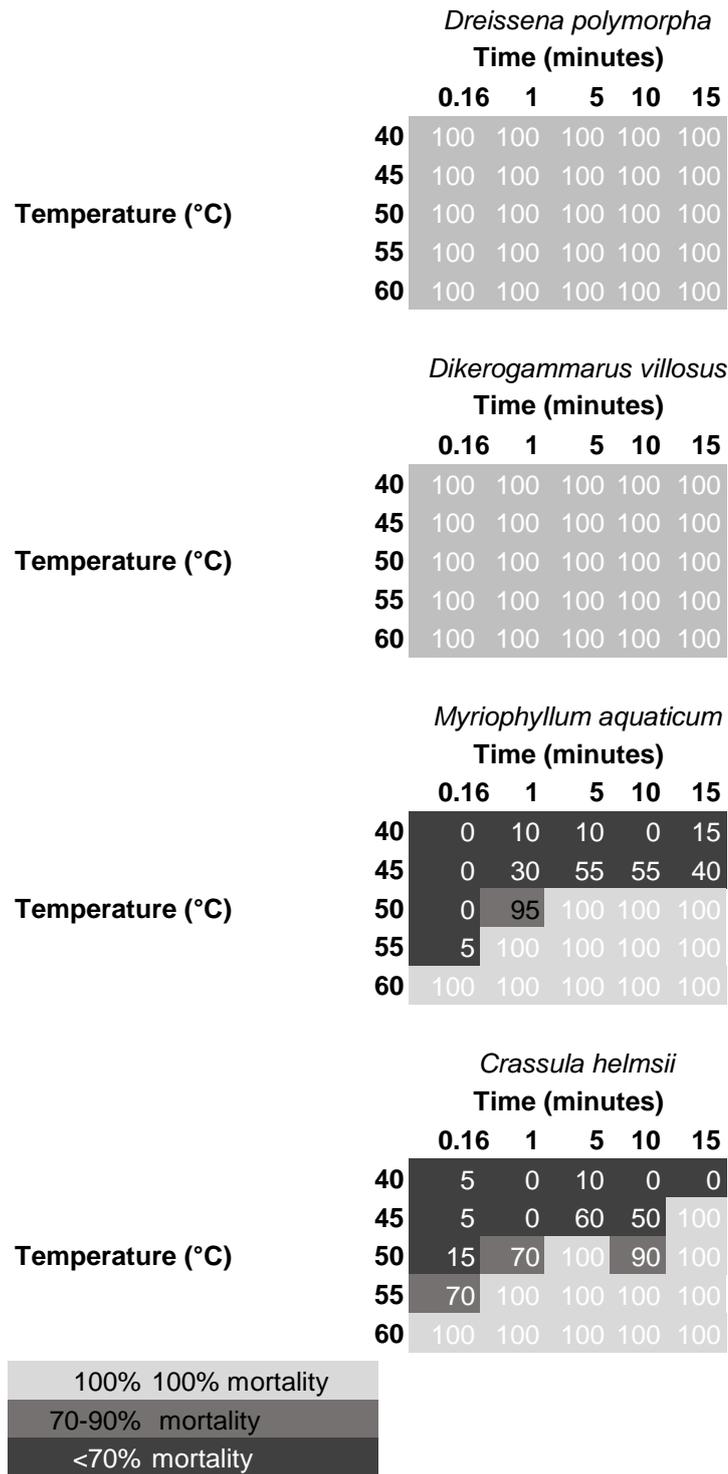


Figure 5.1 Heat map illustrating percentage mortality of both plant and animal species after immersion in hot water at different temperatures and treatment durations.

5.5 Discussion

Soaking equipment and footwear in hot water represents a safe, practical cleaning protocol to improve the rapidity and effectiveness of *Check Clean Dry* biosecurity (Stebbing et al. 2012; Anderson et al. 2015). Stakeholder interviews have identified a need to minimise time spent on biosecurity, particularly for organisations where staff time spent on biosecurity imposes an economic cost and who want to optimise the work patterns of staff in the field (Sutcliffe et al. 2017). Therefore, any reduction in the time required to undertake the 'Clean' phase of *Check Clean Dry* is likely to improve biosecurity uptake. The effectiveness of hot water treatments in killing propagules of four aquatic IAS species was examined, and the treatments were applied using hot water in large buckets to simulate probable domestic or field depot situations. Our results indicate that hot water caused mortality in all the invaders, but with some variation in temperature required to cause total mortality, likely reflecting different thermal tolerance. Immersion in hot water of 45°C for 15 minutes caused 100% mortality of both *Dreissena polymorpha* and *Dikerogammarus villosus*, in accord with previous studies conducted by Stebbing et al. (2011) and Anderson et al. (2015), and mortality was 100% even with shorter treatment times. However, temperatures of 50°C or above for 15 mins were required to cause high mortality (90-100%) of the IAS plant propagules. We conclude that treatment of 45°C for periods shorter than 15 minutes is less effective than treatment for the recommended 15 minutes. Therefore, any reduction in treatment duration at the suggested 45°C would not cause consistent and high mortality across IAS.

Mortality was higher at higher temperatures, and in fact high (90-100%) mortality was achieved for all species following immersion in water at 55°C or 60°C for 5 minutes. Temperatures of 55°C or 60°C could potentially be applied in a depot or laboratory setting where facilities and training are provided for safe working practices, and these temperatures would lead to high mortality of IAS propagules. In particular, the findings show that at temperatures above 50°C, shorter immersion times lead to high mortality. This may be important in increasing the uptake of biosecurity practices when time is a constraint.

However, such conditions are unlikely to be met in domestic settings (e.g. to treat recreational equipment or personal clothing) or in the field. Recommendations for the temperature of water from a hot tap are based on safety. Temperatures exceeding 51.66°C can pose a serious risk of severe burn to adults and children (Feldman et al. 1998), whilst the World Health Organisation recommend water should be no less than 50°C to minimise the risk of *Legionella* bacteria in water. The temperature of hot water in domestic settings is variable. However, to

ensure uptake and application of biosecurity, practices need to be easy to apply and it is important that guidance is simple, consistent and safe (Sutcliffe et al. 2017). Therefore, for practical application in field or domestic conditions, we recommend that a minimum temperature of 50°C is used where feasible for biosecurity with a minimum treatment time of 5 minutes, and with longer immersion times if practical. Although this treatment may not cause 100% mortality, it represents a safe compromise between ease of use, safety and effectiveness.

The availability of facilities for *Check Clean Dry* has also been identified as a barrier to good biosecurity (Sutcliffe et al. 2017). We recommend investment in cleaning stations that include hot water facilities to enable those working or undertaking recreational activities in the environment to clean their equipment. In the absence of any specialist biosecurity facilities, using hot tap water as part of the *Check Clean Dry* protocol will reduce the risk of IAS transmission, even if the water temperature does not reach 50°C. Immersion in hot water is a simple treatment for small equipment. However, there is also a need for practical biosecurity treatments that can be applied to large equipment such as boats and machinery. High pressure sprays are used to clean fouling organisms from boats, with hot water high pressure sprays reported to kill fouling animals *Dreissena polymorpha*, and *Dreissena bugensis* (quagga mussel) (Morse 2009; Comeau et al. 2011; Stebbing and Rimmer 2014). We recommend that further research is carried out into the effectiveness of cold and hot water sprays in dislodging propagules and in causing mortality of high impact plant as well as animal IAS, particularly as not all propagules may be removed.

Clean Drain Dry and *Check Clean Dry* campaigns aim to raise biosecurity awareness and practice among water users, to reduce the risk of IAS spread. Awareness of these campaigns has been shown to lead to people being more likely to carry out good biosecurity measures than those who are not aware of campaigns (Anderson et al. 2014; Defra 2018). Time constraints have been identified as a barrier to good biosecurity especially in large organisations with financial constraints (Sutcliffe et al. 2017). This study indicates that high mortality of IAS plants and animals can be achieved with shorter treatment times of 5 minutes, if temperatures above 50°C are applied. Furthermore, even lower temperature treatments of 45°C caused >40% mortality and will therefore substantially reduce the risk of IAS introduction and spread. Environmental organisations are under a range of pressures to decrease costs whilst also undertaking and demonstrating good environmental stewardship. The development of time efficient and effective biosecurity practices will make an important contribution to biosecurity uptake and to slowing the introduction and spread of IAS.

5.6 References

- Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD. 2015. Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biol Invasions* 2287–2297. doi: 10.1007/s10530-015-0875-6
- Anderson LG, White PCL, Stebbing PD, et al. 2014. Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLoS One* 9:1–10. doi: 10.1371/journal.pone.0092788
- Barbour JH, McMenamin S, Dick JTA, et al. 2013. Biosecurity measures to reduce secondary spread of the invasive freshwater Asian clam, *Corbicula fluminea* (Muller, 1774). *Manag Biol Invasions* 4:219–230. doi: 10.3391/mbi.2013.4.3.04
- Beyer J, Moy P, Stasio B De. 2011. Acute Upper Thermal Limits of Three Aquatic Invasive Invertebrates: Hot Water Treatment to Prevent Upstream Transport of Invasive Species. *Environ Manage* 47:67–76. doi: 10.1007/s00267-010-9573-4
- Branson J. 2006. *Didymosphenia geminata* economic impact assessment: Wellington, New Zealand, New Zealand Institute of Economic Research Report. Wellington
- Caffrey JM, Baars J-R, Barbour JH, et al. 2014. Tackling Invasive Alien Species in Europe: The top 20 issues. *Manag Biol Invasions* 5:1–20. doi: 10.3391/mbi.2014.5.1.01
- Comeau S, Rainville S, Baldwin W, et al. 2011. Susceptibility of quagga mussels (*Dreissena rostriformis bugensis*) to hot-water sprays as a means of watercraft decontamination. *Biofouling* 27:267–274. doi: 10.1080/08927014.2011.564275
- Dan T, KrishnaRaj S, Saxena P. 2000. Metal Tolerance of Scented Geranium (*Pelargonium* sp. “Frensham”): Effects of Cadmium and Nickel on Chlorophyll Fluorescence Kinetics. *Int J Phytoremediation* 2:91–104. doi: 10.1080/15226510008500032
- Defra. 2015. The Great Britain Invasive Non-native Species Strategy. York
- Dudgeon D, Arthington AH, Gessner MO, et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biol Rev Camb Philos Soc* 81:163–82. doi: 10.1017/S1464793105006950
- Dunn AM, Hatcher MJ. 2015. Parasites and biological invasions: Parallels, interactions, and control. *Trends Parasitol* 31:189–199. doi: 10.1016/j.pt.2014.12.003

- Feldman KW, Schaller RT, Feldman JA, Mcmillon M. 1998. Tap water scald burns in children. *Inj Prev* 4:238–242
- Firth D. 1993. Bias Reduction of Maximum Likelihood Estimates. *Biometrika* 80:27–38. doi: 10.2307/2336755
- Gallardo B, Aldridge DC. 2013. The “ dirty dozen ”: socio-economic factors amplify the invasion potential of 12 high-risk aquatic invasive species in Great Britain and Ireland. *J Appl Ecol* 50:757–766. doi: 10.1111/1365-2664.12079
- Heinze G, Ploner M. 2016. logistf: Firth’s Bias-Reduced Logistic Regression. R package version 1.22
- Hetherington S., Smillie RM. 1982. Humidity-sensitive degreening and regreening of leaves of *Borya nitida* Labill. as followed by changes in chlorophyll fluorescence. *Aust J Plant Physiol* 9:587–599
- Lockwood JL, Cassey P, Blackburn T. 2005. The role of propagule pressure in explaining species invasions. *Trends Ecol Evol* 20:223–228. doi: 10.1016/j.tree.2005.02.004
- Morse JT. 2009. Assessing the effects of application time and temperature on the efficacy of hot-water sprays to mitigate fouling by *Dreissena polymorpha* (zebra mussels Pallas). *Biofouling* 25:605–610. doi: 10.1080/08927010902989245
- Perrings C, Mooney H, Williamson M. 2009. The Impact of Invasive Alien Species on Ecosystem Services and Human Well-being. In: *Bioinvasions and Globalization: Ecology, Economics, Management, and Policy*. Oxford University Press, Oxford, pp 161–173
- R Core Team. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Ricciardi A, Maclsaac HJ. 2010. Impacts of Biological Invasions on Freshwater Ecosystems. In: *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*. Blackwell Publishing Ltd, Sussex, pp 211–224
- RStudio Team. 2016. RStudio: Integrated Development for R
- Scherer R. 2018. PropCIs: Various Confidence Interval Methods for Proportions. R package version 0.3-0

- Stebbing P, Irving S, Stentiford G, Mitchard N. 2012. A review of potential methods to control and eradicate the invasive gammarid, *Dikerogammarus villosus* from UK waters. Weymouth, UK
- Stebbing P, Rimmer G. 2014. Pressure washer use in the control of aquatic invasive non-native species. Cefas, Weymouth, UK
- Stebbing P, Sebire M, Lyons B. 2011. Evaluation of a number of treatments to be used as biosecurity measures in controlling the spread of the invasive killer shrimp (*Dikerogammarus villosus*): Final report (September 2011). Weymouth, UK
- Sutcliffe C, Quinn CH, Shannon C, et al. 2017. Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biol Invasions* 20:. doi: 10.1007/s10530-017-1541-y
- Tidbury HJ, Taylor NGH, Copp GH, et al. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biol Invasions* 18:3277–3292. doi: 10.1007/s10530-016-1219-x
- Vander Zanden MJ, Olden JD. 2008. A management framework for preventing the secondary spread of aquatic invasive species. *Can J Fish and Aquat Sci* 65:1512–1522. doi: 10.1139/F08-099
- Waterkeyn A, Vanschoenwinkel B, Elsen S, Anton-pardo M. 2010. Unintentional dispersal of aquatic invertebrates via footwear and motor vehicles in a Mediterranean wetland area. *Aquat Conserv Mar Freshw Ecosyst* 587:580–587. doi: 10.1002/aqc.1122
- Willits DH, Peet MM (2001) Measurement of chlorophyll fluorescence as a heat stress indicator in tomato: laboratory and greenhouse comparisons. *J Amer Soc Hort Sci* 126:188–194. doi: <https://doi.org/10.1007/s11099-005-0161-4>
- Zieritz A, Gallardo B, Baker SJ, et al (2016) Changes in pathways and vectors of biological invasions in Northwest Europe. *Biol Invasions* 19:1–14. doi: 10.1007/s10530-016-1278-z

Chapter 6: The effectiveness of e-Learning on stakeholder awareness, risk perception and self-reported behaviour in relation to biosecurity to slow the spread of invasive alien species

6.1 Abstract

The Convention on Biological Diversity (CBD) recognises that there is an urgent need to address the issue of invasive alien species (IAS). Prevention measures including biosecurity are essential to reducing the introduction and spread of IAS and are central to international and national IAS policy. The UK as a contracting party to the CBD has implemented regulatory and voluntary instruments to address the issues of IAS in an attempt to slow the spread of introduction and secondary spread. These include campaigns and e-Learning training which attempt to increase awareness and encourage pro-environmental behaviours among stakeholders. This paper is the first to evaluate the effectiveness of e-Learning as a tool to increase awareness, risk perception and self-reported biosecurity behaviour among field researchers in relation to IAS. We surveyed field researchers (a mixture of students and professionals) before and six months after undertaking an e-Learning course on IAS and biosecurity practices. Awareness of IAS and self-reported biosecurity behaviour increased after e-Learning among students and professionals. Students had a lower awareness of IAS than professionals before training (20% of students vs 60% of professionals), but after training students showed a greater increase in awareness which led to similar levels of awareness post-training (81%). Prior to training, risk perception was also lower amongst students than professionals (33% of students and 59% of professionals were aware of the risk that their activities posed to the accidental spread of IAS). There was no change in risk perception amongst professionals after training, however training led to a doubling of risk perception in students. e-Learning also led to an increase in reported biosecurity behaviour and cleaning practices, with higher levels of biosecurity cleaning amongst professionals. The higher awareness and better biosecurity amongst professionals is likely to reflect their familiarity with the issues of IAS and day to day activities in the field. Our results suggest that e-Learning is an effective tool to raise awareness and encourage behaviour change among field researchers in an attempt to reduce the risk of accidental introduction and spread of IAS.

6.2 Introduction

6.2.1 Invasive Alien Species and biosecurity

According to the Convention on Biological Diversity (CBD) non-native species that have negative ecological, economic or social impacts, or adversely affect human health in their

novel range are termed Invasive Alien Species (IAS) (the term IAS is synonymous with invasive non-native species (INNS). IAS can have negative environmental impacts on native species, and are a leading cause of biodiversity loss globally (Simberloff et al. 2013). The economic impacts of IAS resulting from loss of productivity, threats to ecosystem services and costs of management are estimated to be approximately €12.5 billion a year in the European Union (Kettunen et al. 2009) and £1.7 billion to the British economy (Williams et al. 2010).

Human activities such as transport, trade and tourism are all associated with pathways of introduction and secondary spread of IAS in the marine, freshwater and terrestrial environment (Hulme 2009; Saul et al. 2017). Once established, control of IAS is difficult and expensive and total eradication is often infeasible (Hulme et al. 2017). Therefore, methods to prevent the risk of introduction and spread are increasingly being recognised as the most cost effective means of reducing the impacts of IAS. Prevention is central to the Convention on Biological Diversity (CBD), EU Marine Strategy Framework Directive (MSFD), EU IAS Regulation (1143/2014) and the Invasive Non-Native Species Strategy for Great Britain (Perrings et al. 2005).

Biosecurity measures are activities aimed at preventing the introduction and secondary spread of IAS; for example good hygiene practices reduce the risk of activities in the field that might lead to the spread of IAS. Biosecurity measures include; ensuring that equipment taken into the field is free from IAS; fieldwork preparation planning (for example visiting an IAS infested site last during a day of site visits, accessing a site to minimise the risk of contaminating vehicles); cleaning measures to remove/kill IAS potentially attached to clothing or equipment (Anderson et al. 2015; Sebire et al. 2018; Shannon et al. 2018a).

To address the issue of IAS and promote good biosecurity behaviour among stakeholders, communication campaigns have been created to raise awareness of the risk of IAS and to modify public attitudes and encourage positive risk-reducing changes in behaviour such as adopting biosecurity measures (pro-environmental behaviour). The *Stop Aquatic Hitchhikers: Clean Drain Dry* campaign in the USA (<http://stopaquatic hitchhikers.org/>) and New Zealand's *Check Clean Dry* campaign (<https://www.mpi.govt.nz/travel-and-recreation/outdoor-activities/check-clean-dry/>) attempt to educate and raise awareness of the impact of accidentally spreading aquatic invasive species among recreational users and to improve biosecurity practice amongst water users. In the UK, the Department for Environment, Food and Rural Affairs (Defra) launched the first invasive species specific biosecurity campaign *Check Clean Dry* in 2010 in response to the first reports of the invasive non-native *Dikerogammarus villosus* (Killer Shrimp) (<http://www.nonnativespecies.org/checkcleandry/index.cfm>). The aim of

the *Check Clean Dry* campaign in the UK (similar to those of the USA and New Zealand) is to raise awareness of the risk posed by stakeholders that use the aquatic environment for work or leisure (e.g. anglers, recreational boaters), and to encourage stakeholders to take practical measures to reduce their risk of accidental introduction and secondary spread of aquatic IAS on equipment (Box 6.1). More recently, a recent survey in the UK on awareness of IAS amongst anglers and boaters had increased over the last 10 years, although awareness remains low amongst public overall (67% general public aware compared to 87% of anglers and 83% of boaters) (Defra 2018). Biosecurity initiatives have also been designed for the terrestrial environment, for example the Forestry Commission in England and Scotland promote the *Keep it Clean* campaign (<https://www.forestry.gov.uk/forestry/bee-h-a6tek3>) which encourages individuals to take measures to reduce the spread of pests and disease.

Box 6.1 Check Clean Dry campaign

Check your equipment, boat and clothing after leaving the water for mud, aquatic animals or plant material, Remove anything you find and leave it at the site

Clean everything thoroughly as soon as you can, paying particular attention to areas that are damp or hard to access. Use hot water if possible.

Dry everything for as long as you can before using elsewhere as some invasive plants and animals can survive for over two weeks in damp conditions.

Since 2010, e-Learning courses have been designed to support the UK's *Check Clean Dry* campaign by raising awareness among stakeholders and targeting behaviours that pose a risk of accidentally spreading IAS in the marine, freshwater and terrestrial environment. The Great Britain Non-Native Species (GBNNS) Secretariat host e-Learning platforms on their website used by government and stakeholders such as anglers, boaters, environmental practitioners and site workers (<http://www.nonnativespecies.org/elearning/>). Field researchers are also an important group of stakeholders that undertake activities in the aquatic and terrestrial environment (e.g. surveying and sampling), which could potentially bring them into

contact with IAS (knowingly or unknowingly) and facilitate their spread (Shannon et al. 2018b; Sutcliffe et al. 2018). The *Better Biosecurity e-Learning course* (2015) designed by the University of Leeds, Cefas, Environment Agency and the GBNNS (https://openeducation.blackboard.com/mooc-catalog/courseDetails/view?course_id=1189_1) targets individuals conducting work activities or research (fieldwork) in the marine, freshwater and terrestrial environment, including students and professionals. With this investment in e-Learning there is an opportunity to investigate their effectiveness in changing the behaviour of participants and fostering more effective biosecurity practices.

6.2.2 Environmental education, training and e-Learning

Education focuses on imparting knowledge and developing an understanding of an issue (Varela-Candamio et al. 2018). Whilst knowledge is a necessary pre-condition for behavioural change it has repeatedly been found that knowledge of an issue alone does not necessarily translate directly into behaviour change to address that problem (Hungerford and Volk 1990; Rothlisberger et al. 2010; McKenzie-Mohr and Schultz 2014). Reasons for this weak association between knowledge and behaviour might be attributed to other factors (e.g. attitude, concern, experience, willingness to act and demographic factors) which can also influence an individuals' ability to take action (McDonald 2014). Instead, research has looked at other ways to foster behaviour change by targeting these other factors through persuasion, incentives, coercion, and training (McKenzie-Mohr and Schultz 2014). Environmental training focuses on increasing an individuals' knowledge (education) as well as providing information for individuals to develop the necessary skills to address the issue at hand and ultimately change behaviours (Michie et al. 2011). Training is described by Salas et al. (2006) as the acquisition of skills and attitudes in addition to knowledge, that lead to improved performance. Therefore, education can be combined with skills training to achieve increased awareness and behaviour change.

E-Learning, or electronic learning, is a method of training that is undertaken at a distance by an individual on a computer or other electronic device (Arkorful and Abaidoo 2014; Azeiteiro et al. 2015). As with traditional training courses, e-Learning courses attempt to educate individuals on individual topics by using real life examples for individuals to relate to, and make connections with their activities (Bouhnik and Marcus 2006; Liaw et al. 2007; Liaw 2008). E-Learning training also supports the delivery of skills information. E-Learning can also be beneficial to individuals (including researchers) that seek professional development but may not have time or money to attend face-to-face courses and undertake laboratory fieldwork training (Bacelar-Nicolau et al. 2009) as it is extremely flexible and can facilitate learning at any time or any place (Lim et al. 2007).

According to Noesgaard and Ørngreen (2015), the most common way to measure effectiveness of training is quantitatively using pre-and post-tests and effectiveness can be defined in many ways (e.g. learning outcome, transfer, attitude, satisfaction). For example Bacelar-Nicolau et al. (2009) measured the effectiveness of e-Learning on knowledge and performance (scores) in higher education; both knowledge and performance increased as well as motivation (willingness) to learn and act also increasing. E-Learning has also been utilised as

an alternative to instructor-led training to meet the fire safety training needs of staff, owners and operators, and research has demonstrated the effectiveness of e-Learning as an alternative to in person training to increase/improve awareness, attitudes and test scores (Harrington and Walker 2009).

Behaviour change is the real purpose behind any training effort compared to education which focuses on increasing knowledge alone; therefore for training to be considered effective, a behavioural change should ideally be observed post-training (Gilpin-Jackson and Bushe 2007). According to Ajzen's Theory of Planned Behaviour (1991), an individuals' behaviour is shaped by attitudes, subjective norms and perceived behavioural control that shape their intention to behave. Training attempts to influence attitudes and increase the individuals' perceived behavioural control by delivering skills information. Studies that have explored the translation of learning into practice have relied on either self-reported instruments of intention to apply behaviour or test scores (Kirkwood and Price 2014) rather than measure actual behaviour. This can be extremely useful in predicting an individuals' intention to act (Marler et al. 2006; Lauzier and Mercier 2018). Despite training investment, the effectiveness of e-Learning in relation to increasing awareness and reported behaviour is yet to be looked at in the context of IAS and biosecurity.

Here we present the first study examining the use of e-Learning in improving IAS awareness and biosecurity practice. By surveying individuals before and after e-Learning, we aimed to investigate the effectiveness of e-Learning training on raising awareness of IAS and/or biosecurity campaigns, changing risk perceptions of field activities accidentally spreading IAS, and improving an individuals' self-reported cleaning and self-reported biosecurity practices.

6.3 Methodology

The *Better Biosecurity e-Learning course* was made freely available on two platforms. The first was available to staff and students at the University of Leeds on an internal Virtual Learning Environment (VLE), 'Minerva'. The second was available on 'Blackboard Open' software, and was aimed at individuals undertaking fieldwork or involved in industry, agriculture, trade, site surveys, education, or recreation. The *Better Biosecurity e-Learning course* took between one to two hours to complete and participants were able to save and return to the course at any time. The course guided the individual through four sections: introduction to IAS and the importance of biosecurity, fieldwork preparation and consideration of the risks of IAS spread, the *Check Clean Dry* campaign, and a set of multiple choice questions. The course's learning objectives to achieve behaviour change were as follows:

1. To make participants aware of the impact of IAS, of routes of IAS spread and of the risk fieldwork poses in relation to introduction and spread.
2. For individuals to gain or advance awareness and knowledge of practical skills for better biosecurity practice.
3. To advance ability to critically evaluate different types of fieldwork scenarios to determine the best methods to reduce the spread of IAS.

The e-Learning course used a mixture of pictures, videos and interactive images in order to engage the individual. Formative multiple choice questions presented during the course allowed users to check their understanding; in the case of an incorrect answer, the individual was shown the correct answer with feedback. At the end of the e-Learning course there were 10 multiple choice questions in which 100% was required in order to pass and receive a completion certificate.

6.3.1 Sampling

At the University of Leeds, staff and students (undergraduate and postgraduate) within relevant disciplines such as geography, environmental studies, biology, ecology and conservation were made aware of the e-Learning course through being sent monthly invitation emails. Students were also introduced to the e-Learning course at induction sessions for undergraduate and postgraduate courses, and in relevant taught modules in the faculties of Environment and of Biological Sciences. The e-Learning was embedded into the Health and Safety risk assessment process for students and staff undertaking fieldwork within these faculties.

Information about the e-Learning course was disseminated externally to a wide range of organisations through email and social media promotions (Twitter and Facebook) during the same time period. Handouts to promote the e-Learning course were also provided at various IAS focused meetings and conferences (e.g. British Ecological Society Annual Meeting, the International Conference on Aquatic Invasive Species), as well as directly targeting organisations that undertake field research (water companies, consultancies, regulators, conservation authorities). The e-Learning course was also promoted on the GBNNS Secretariat website and the University of Leeds website. All participation on the e-Learning course was voluntary.

6.3.2 Survey design

After enrolling on to the course, participants were asked to undertake the pre e-Learning online survey; this was optional and participants were able to start the e-Learning without having to complete the survey.

All individuals were asked whether they would be willing to participate in a post e-Learning survey. All individuals that agreed to be contacted for a follow up survey were emailed 6 months after completing the pre e-Learning survey and Better Biosecurity e-Learning course. This time interval was used to allow participants the opportunity to apply their new behaviour at work/study before we measured any behaviour change. Both e-Learning platforms (the VLE and Blackboard Open) were cross-checked against participants that agreed to be followed up to check that the e-Learning had been fully completed before participants were emailed the link to the post e-Learning survey.

For comparison of awareness of IAS and/or biosecurity campaigns, risk perception of field activities, self-reported cleaning and self-reported biosecurity practice, identical questions were asked in the pre and post e-Learning online survey (Appendix K).

The surveys were created using Online Surveys software (www.onlinesurveys.ac.uk/). The online surveys satisfied the University of Leeds' guidelines on ethical conduct (Ethics reference BIOSCI 15-023). All data was downloaded from Online Surveys, saved and encrypted for analysis. A pilot study (internal $n=5$, external $n=5$) was conducted to ensure the pre and post surveys worked effectively and to reduce ambiguity or misinterpretation of the questions. This pilot data was not used in the overall analysis.

The pre e-Learning surveys were conducted between November 2015 and July 2018 and were designed to take no longer than 10 minutes. Post e-Learning surveys were conducted 6 months after the individual had completed the initial survey and training.

Surveys included a one page introductory information sheet about the project aims and objectives and stated that participants would not be identifiable in the research outputs. Due to a variety of different definitions used for IAS in the literature (including INNS and non-indigenous species), a definition of IAS was given at the start of the online survey. Participants were asked for consent before being able to continue with the survey.

6.3.2.1 Demographic data

The first section of the survey collected demographic data on the participants (gender and age). Participants who took the training on Blackboard Open were asked to identify what organisation they worked for, participants who took the training on the VLE were known to be working or studying at the University of Leeds. All participants were asked if they were studying; if yes, participants were asked for their department and affiliation and at the level of education (undergraduate, postgraduate, PhD).

6.3.2.2 Self-reported biosecurity cleaning practices

The second section of the survey focused on self-reported biosecurity cleaning practices undertaken by respondents. There are many difficulties with measuring actual behaviour using surveys, therefore researchers rely on reported behaviour in an attempt to get closer to reality (Corral-Verdugo 1997). To increase the value of participants' answers and to increase accuracy, questions concerning the cleaning of equipment, transport and clothing were asked before participants answered questions on IAS and biosecurity behaviour. This was to avoid participants changing answers in relation to the research question on what they would think might be a more socially desirable answer.

All participants were asked if they used equipment in the field (yes or no). To determine self-reported cleaning practices, participants that answered yes to using equipment in the field were then asked questions about cleaning practices for equipment. Participants were asked a series of questions (based on the *Check Clean Dry* campaign) about how often they cleaned equipment before arriving and before leaving a site, as well as whether they dried equipment between uses and if they used the same equipment at multiple sites a day (measured using a Likert scale from always to never). Participants were given a selection of cleaning methods to choose from and were able to choose as many methods of cleaning equipment that they undertook. These included measures such as rinsing in cold water, cleaning with disinfectant and drying either before arriving at a site, before leaving a site or upon returning after fieldwork.

All participants were asked how they arrived at field sites. Participants that arrived by car/bicycle/other wheeled vehicles and by boat were then asked questions about how often they cleaned tyres/wheels/boat hulls before arriving and before leaving a site as well as whether they dried transport between uses (again using a Likert scale from always to never). Participants were again allowed to choose the method that they took to clean transport before arriving at a site, before leaving a site or upon returning after fieldwork. Participants that did

not arrive by car/bicycle/other wheeled vehicle or by boat in the field were automatically forwarded to answer questions about cleaning practices for outerwear/footwear.

All participants were asked how often they cleaned footwear and outerwear in-between site visits (Likert scale from always to never), and what cleaning methods they used. These included measures such as rinsing in cold water, cleaning with disinfectant and drying either before arriving at a site, before leaving a site or upon returning after fieldwork.

All cleaning questions for equipment, transport and footwear/outerwear were used to generate a 'self-reported cleaning score' for the analysis. The response given to how often participants cleaned before arriving, before departing, after returning and dried in between was scored from 0-4 (e.g. never = 0, rarely = 1, sometimes = 2, often = 3, always = 4). For each variable (equipment, transport and footwear/outerwear) each respondent was given a mean score and then an overall combined score. Participants that did not complete all variables were given a mean score based on one, or both of the other variables. The higher the score the better the self-reported biosecurity cleaning practices of the individual.

6.3.2.3 Awareness of IAS and biosecurity campaigns

To measure awareness, participants were asked if they were aware of IAS and/or any campaigns in relation to biosecurity (yes/no). If participants answered yes, they were then asked to give further explanation and details.

6.2.3.4 Risk perception of activities accidentally spreading IAS

Risk perceptions are fundamental components that are influenced by, and frame attitudes and beliefs, and can help predict intentions and behaviours (O'Connor et al. 1999; Estévez et al. 2015). To determine risk perception, participants were asked whether they considered their field activities to pose a risk in terms of spreading IAS (yes or no). Those that answered yes were asked to rank their risk from low (1) to high (5).

6.2.3.5 Self-reported biosecurity practice

The final section of the survey asked all respondents to self-report on whether they consciously employed biosecurity measures in the field (yes or no). Asking individuals to self-report on their behaviour allowed us to investigate whether e-Learning had an effect on self-reported biosecurity practice as self-reporting has been recognised as an important factor in achieving behaviour change (Corral-Verdugo 1997).

6.3.3 Data analysis

A total of 666 individuals completed the survey. However, fewer individuals provided information that enabled us to carry out an analysis ($n=62$) on paired data. Therefore, the whole data set was analysed as well as analysis on the paired data.

All statistical analyses were carried out in R version 3.5.0 (R Core Team 2016) with $\alpha = 0.05$. We investigated the effect of training and position (student or professional) on an individual's awareness, risk perception, self-reported biosecurity cleaning practices and self-reported biosecurity practice. Models investigating awareness, risk perception and self-reported biosecurity practices were investigated using a binomial error structure and data were not over dispersed. Respondents reported their cleaning practices on a Likert scale, and the replies to these questions were then used to generate a composite cleaning score. Parametric analysis of Likert scale data is common in the literature (Goodwin et al. 2018), and our data comprised a composite score. Therefore, a parametric approach was used, having the advantage of allowing exploration of potential interaction terms. Models investigating self-reported biosecurity cleaning practices used a Gaussian error structure as data were normally distributed. GLMs were simplified to minimum adequate models (MAMs) (Crawley 2007). Variables were discarded from the model when they did not significantly increase deviance χ^2 and F tests for significance were then employed for binomial and Gaussian models. However, as Likert scale data are in fact ordinal data, we also undertook non-parametric analyses. Self-reported biosecurity cleaning practices were also tested using non-parametric tests e.g. Mann Whitney U test.

All paired analysis were carried out in R version 3.5.0 with $\alpha = 0.05$. Again, we investigated the effect of training and position on an individual's awareness, risk perception, self-reported biosecurity cleaning and self-reported biosecurity practice and used both parametric and non-parametric tests to explore the cleaning scores.

6.4 Results

6.4.1 Pre and post survey return rate and demographics

A total of 666 individuals completed the pre e-Learning survey; of these individuals 461 (69%) were students and 205 (31%) were professionals. Students included individuals undertaking undergraduate (56%), taught postgraduate (27%) and PhD studies (27%). Professionals included practitioners and volunteers working in the field of conservation and environmental management, academic lecturers and field staff.

A total of 14 different universities and research institutes were represented by the students; 10 in the UK, 1 in Ireland, 1 in Germany and 2 in the USA. Among the professionals, 124 different organisations and companies were represented, as were participants that were self-employed and retired. Organisations were based worldwide and included UK, USA, Australia, Mexico, Holland, Kenya, Norway, New Zealand, and India.

A range of age groups were represented in the pre e-Learning survey, with the majority of participants aged between 18-25 (63%) then 26-35 (16%) followed by 36-45 (9%), 46-55 (6%) and finally 66 or over (1%) (0.3% preferred not to say).

All participants were asked to select up to four disciplinary areas that best described their area of work, research or education (Figure 6.1). The most common discipline selected was Biology (37%), followed by Ecology (35%), Conservation (29%) and Environmental Science (18%).

Please note that the totals sum up to >100% as participants could select more than one discipline.

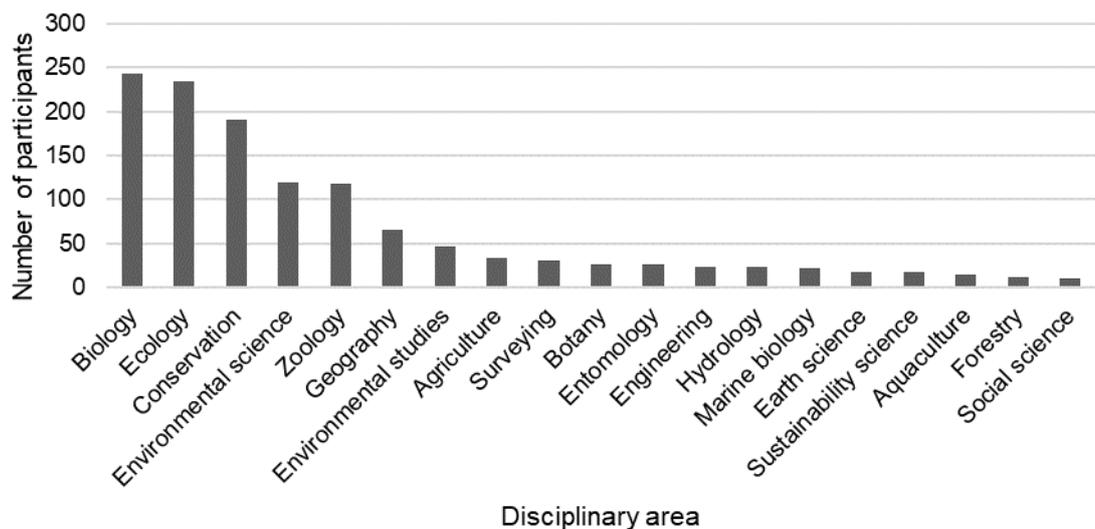


Figure 6.1 Disciplinary area represented by all participants (note that participants could choose up to 4 disciplinary areas)

A total of 274 participants agreed to participate in the follow up survey. Of these, 78 participants completed the post e-Learning survey of which 32 (41%) were students and 46 (59%) were professionals.

6.4.2 The effect of training on awareness of IAS and/or biosecurity campaigns

Participants were asked before and after the e-Learning course whether they were aware of IAS and/or campaigns in relation to biosecurity. Awareness of IAS and/or biosecurity campaigns increased after undertaking the e-Learning course (Table 6.1). Before e-Learning, 32% of participants were aware of IAS and/or biosecurity, this increased to 81% of participants after e-Learning.

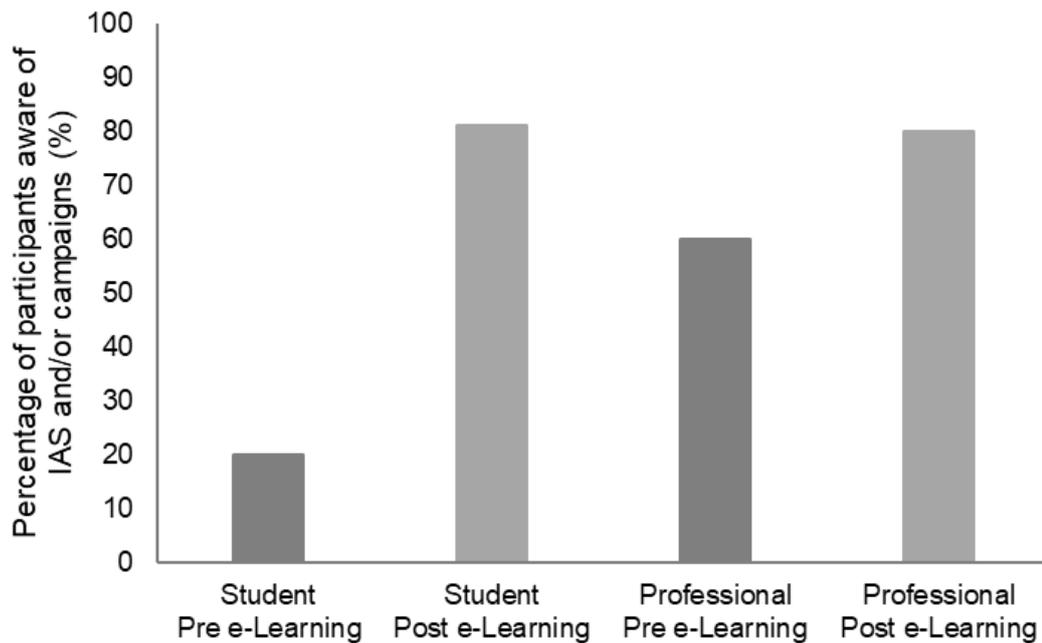


Figure 6.2 Percentage of students and professionals that were aware of IAS and/or campaigns pre and post e-Learning

Awareness was significantly affected by the interactions between position (student or professional) and training (Table 6.1). Initial awareness was higher in professionals (60%) than students (20%). However, students had a greater increase in awareness after e-Learning compared to professionals, leading to a similar awareness post-training; student awareness increased to 80% and professional's awareness increased to 81% (Figure 6.2).

Participants that were aware of campaigns (or guidance) gave examples of Check Clean Dry, Be Plant Wise, ballast water management, EU IAS Regulation (1143/2014) and Forestry Commission guidance.

6.4.3 The effect of training on risk perception

Participants were asked whether they considered their activities to pose a risk of accidentally spreading IAS. Before undertaking the e-Learning course, 41% of participants considered their activities to pose a risk to accidentally spreading IAS, this increased to 56% after e-Learning.

Before e-Learning, those that did consider their activities a risk considered it a medium to low risk on the Likert scale. After e-Learning participants that considered their activities to pose a risk considered it a medium to high risk on the Likert scale.

Risk perception was also significantly affected by the interaction between position and training (Table 6.1). Initial risk perception was higher among professionals (59%) compared to students (33%). Interestingly, whilst student's risk perception doubled after e-Learning (66%) ($\chi^2=13.61$, $df=1$, $p<0.05$), risk perception of professionals' did not change significantly ($\chi^2=1.11$, $df=1$, $p=0.29$) (Figure 6.3).

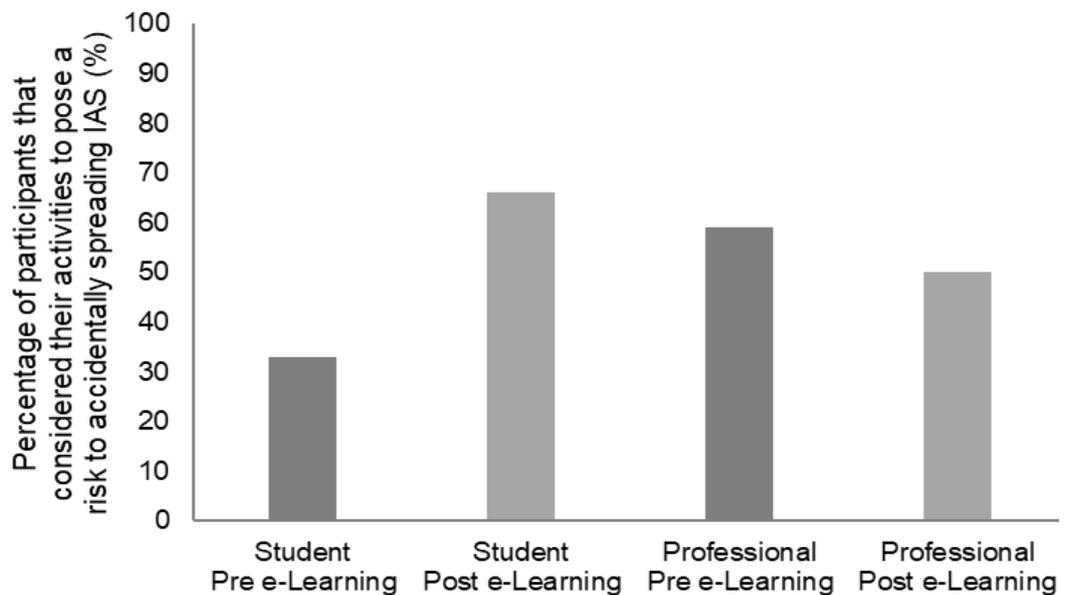


Figure 6.3 Percentage of students and professionals that considered their activities to pose a risk to accidentally spreading IAS pre and post e-Learning

6.4.4 The effect of training on self-reported biosecurity practice

Participants were asked before and after e-Learning whether they consciously employed biosecurity measures in the field. Self-reported biosecurity practice increased after undertaking the e-Learning course (Table 6.1). Before e-Learning, 42% of participants reported consciously employing biosecurity measures in the field, this increased to 81% after e-Learning. Self-reported behaviour was higher amongst professionals than amongst students (Figure 6.4) but was not significantly affected by the interactions between position and training (Table 6.1).

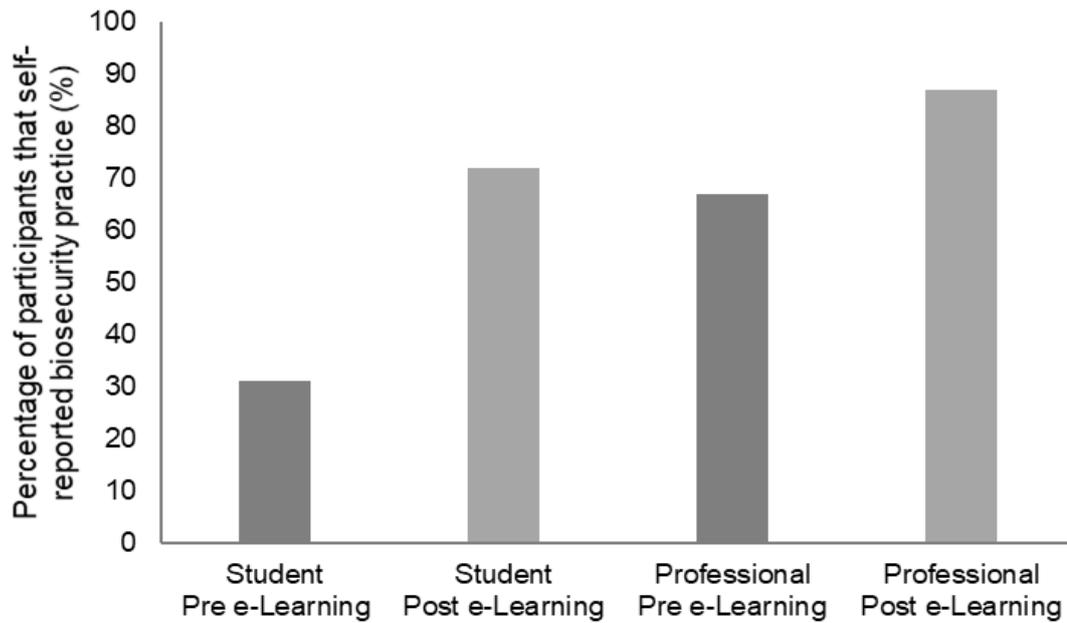


Figure 6.4 Percentage of students and professionals that self-reported biosecurity practice pre and post e-Learning

6.4.5 The effect of training on self-reported cleaning behaviour

Answers to questions on how they cleaned equipment, transport and footwear/outerwear were used to calculate a cleaning score for each participant before and after e-Learning. The overall mean cleaning score increased after training ($F=11.54$, $df=1,742$, $P<0.05$).

Self-reported cleaning behaviour was higher for professionals than students, and there was no significant effect of the interaction between position and training (Figure 6.5, Table 6.1).

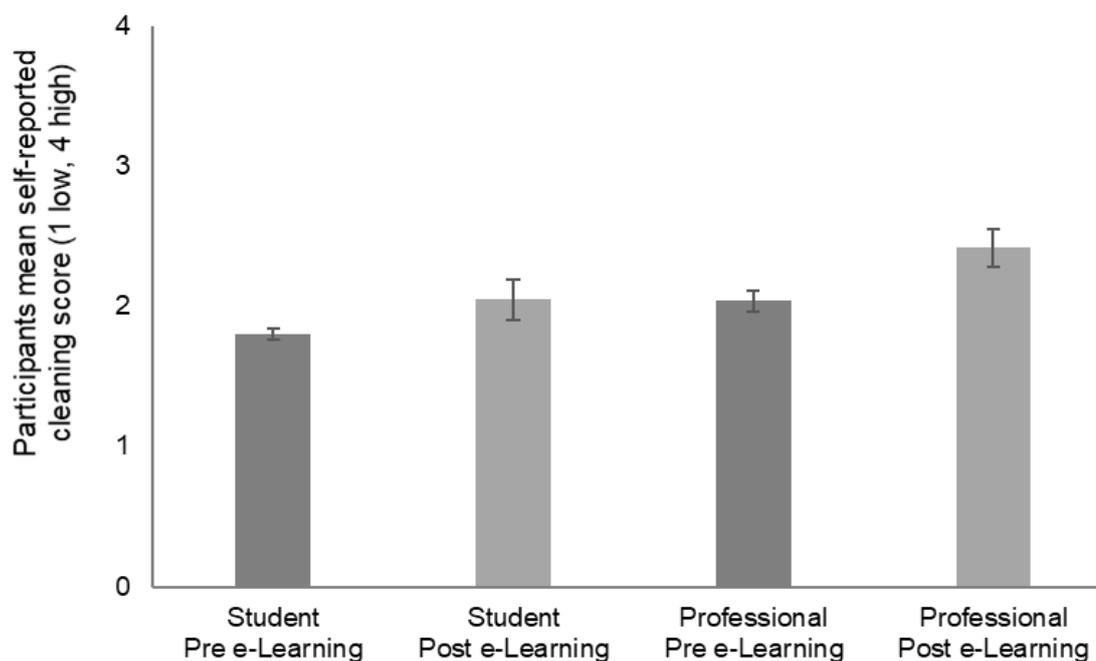


Figure 6.5 Mean self-reported cleaning behaviour of students and professionals pre and post e-Learning

The result of the non-parametric analysis were in accord with those of the parametric analysis. A Mann-Whitney U test was used to explore the effects of training on self-reported cleaning behaviour; training had a significant effect on self-reported cleaning behaviour ($U=19878$, $p<0.05$), and position had a significant effect on self-reported cleaning behaviour ($U=44233.5$, $p<0.05$) where cleaning scores were higher for professionals than for students.

Table 6.1 The influence of position on awareness, risk perception, self-reported biosecurity practice and self-reported cleaning behaviour

Awareness				
	Estimate	Std. Error	z value	P
Training	4.7228	1.0166	4.646	<0.05
Position	3.6823	0.6923	5.319	<0.05
Training:Position	-1.8675	0.6142	-3.040	<0.05
Risk perception				
	Estimate	Std. Error	z value	P
Training	3.0964	0.8371	3.699	<0.05
Position	2.7946	0.5877	4.755	<0.05
Training:Position	-1.7206	0.5054	-3.404	<0.05
Self-reported biosecurity practice				
	Estimate	Std. Error	z value	P
Training	2.3207	0.9343	2.484	<0.05
Position	2.1050	0.6897	3.052	<0.05
Training:Position	-0.5731	0.6153	-0.931	0.35
Self-reported cleaning behaviour				
	Estimate	Std. Error	t value	P
Training	0.2481	0.1493	1.661	<0.05
Position	0.2396	0.0834	2.872	<0.05
Training:Position	0.1296	0.2223	0.583	0.56

6.4.6 Paired comparisons

A total of 62 individuals completed the pre e-Learning survey and post survey; of these individuals, 23 (37%) were students and 39 (63%) were professionals.

6.4.6.1 The effect of training on awareness of IAS and/or biosecurity campaigns

Awareness was significantly affected by the interactions between position and training (Table 6.2). Again, professionals had a greater awareness of IAS and/or campaigns before and after training.

82% of professionals that returned for the follow up survey were aware of IAS and/or campaigns before training compared to only 66% of professionals that were aware before training who did not complete the follow up survey.

Likewise, 65% of students that returned for the follow up survey were aware of IAS and/or campaigns before training compared to 16% of students that were aware before training who did not complete the follow up survey. This increased to 87% awareness after training. This highlights some areas of concern for self-selection bias in the analysis, where these participants had higher awareness of IAS and/or campaigns before training compared to those that did not return. However, the results of the analysis of the paired and the overall data set

were in accord; awareness was significantly affected by position, by training and by the interaction.

6.4.6.2 The effect of training on risk perception

Professionals considered their activities more of a risk compared to students before training; 77% of professionals considered their activities to pose a risk before training compared to 52% of students. After training, student's risk perception increased to 65% who considered their activities a risk but decreased to 59% for professionals. Risk perception was not significantly affected by position, training or by the interaction (Table 6.2).

6.4.6.3 The effect of training on self-reported biosecurity practice

Paired self-reported biosecurity practice was significantly affected by the interactions between position and training (Table 6.2). Again, professionals had greater self-reported biosecurity practices, and biosecurity practice improved after training. Amongst professionals that returned for the follow up survey, self-reported biosecurity practices increased from 79% before, to 87% after training. Likewise, amongst students, self-reported biosecurity practices increased from 26% before training to 78% after training.

6.4.6.4 The effect of training on self-reported cleaning behaviour

Finally, self-reported cleaning behaviour was higher for professionals than students. There was no significant effect of training on cleaning behaviour and no significant interaction (Table 6.2). The results of the non-parametric analysis are in accord with this. There was no significant effect of training on self-reported cleaning behaviour; (Mann-Whitney $U=1691.5$, $p=0.249$). However there was a significant difference between professionals and students, with self-reported cleaning behaviour higher among professionals ($U=1175.0$, $p<0.05$).

Table 6.2 The influence of position on awareness, risk perception, self-reported biosecurity practice and self-reported cleaning behaviour

Awareness				
	Estimate	Std. Error	z value	P
Training	2.3390	0.7523	3.109	<0.05
Position	1.9617	0.5973	3.284	<0.05
Training:Position	-2.5042	0.9473	-2.644	<0.05
Risk perception				
	Estimate	Std. Error	z value	P
Training	-0.321	0.4178	-0.819	0.413
Position	0.4890	0.4995	0.979	0.328
Training:Position	-1.7458	0.9308	-1.876	0.061
Self-reported biosecurity practice				
	Estimate	Std. Error	z value	P
Training	22.955	3.988	5.755	<0.05
Position	22.281	3.705	6.283	<0.05
Training:Position	-11.345	4.736	-2.395	<0.05
Self-reported cleaning behaviour				
	Estimate	Std. Error	t value	P
Training	0.1624	0.1632	0.995	0.322
Position	0.5791	0.1847	3.135	<0.05
Training:Position	-0.2104	0.7176	-0.293	0.770

6.5 Discussion

E-Learning is increasingly being used as a method of environmental training to raise awareness and change behaviours among individuals. E-Learning is a useful tool in the environmental sciences and other disciplines as many individuals seek professional development online as they do not always have time to attend face-to-face training courses (Bacelar-Nicolau et al. 2009). The *Better Biosecurity e-Learning course* was developed in 2015 to raise awareness and encourage uptake of biosecurity practices among field researchers who undertake activities in the marine, freshwater and terrestrial environment. Nearly 5 years on, this study is the first to test the effectiveness of the course on awareness and reported pro-environmental behaviour change in relation to biosecurity practices to reduce the risk of accidentally spreading IAS. Applying a common measurement of effectiveness, we measured field researchers' awareness, risk perception, self-reported biosecurity practice and self-reported cleaning behaviour before, and 6 months after completing the course. We conclude that the e-Learning course increased awareness and participants reported higher biosecurity scores after e-Learning.

In the literature, studies have found mixed results on the impacts of training on awareness. In a study looking at students' awareness of plagiarism and their perception of the seriousness of plagiarism before and after completing an online academic integrity training

course, both students' awareness of plagiarism and their perceptions increased significantly after completing the training (Curtis et al. 2013). However, in a case study of two electricity companies, Perron et al. (2006) found that environmental awareness training in business did not sufficiently increase employee environmental awareness of the company's environmental impacts. Perron et al. (2006) argue that having the training alone is not enough and it must be supported by tools and other efforts which will improve performance. Consistent with Curtis et al. (2013), our study found as expected, that participants' awareness increased following training and professionals had higher awareness compared to students. Higher levels of awareness among practitioners may be explained by infrastructure availability as well as an increase in interest and usefulness of the training topic compared to students (Grossman and Salas 2011; Grossman and Burke-Smalley 2018).

When we explored the data from all respondents we also found that risk perceptions were higher among professionals before e-Learning compared to students. Similarly, in a study looking at the risk perceptions of field researchers, Shannon et al. (2018) found higher risk perceptions among those who undertook high risk activities in relation to IAS (sampling and aquatic fieldwork). Interestingly, whilst overall risk perception increased after training, professionals' risk perception did not change significantly following e-Learning unlike students' risk perceptions which increased. Previous studies have also found that simply being aware of risks does not always seem to be a strong factor for initiation of behaviours that reduce risk (Karanci et al. 2006). Wachinger et al. (2013) argue that whilst personal experience (of a natural hazard) has the most substantial impact on risk perception however, if after training individuals do not have any negative experience, then they are more likely to believe that a future event will unlikely affect them, therefore their risk perception is unaltered and has the potential to decrease. We therefore argue that professionals' risk perception did not change significantly as a result from training due to the increase in awareness and continued experience and familiarity of IAS in the field.

Education is more than just the provision of information which does not always lead to behaviour change (Burke and Hutchins 2007; Hutchins and Burke 2007). Training aims to bridge this gap and provide participants with skills information to encourage individuals to act in an environmentally responsible manner (Shaw et al. 1999; Noesgaard and Ørngreen 2015). We found that self-reported biosecurity (measured as self-reported biosecurity practice and self-reported cleaning) improved after training, supporting our assumptions that training led both to increased awareness and to reported behavioural change. In our study we also found that professionals reported higher levels of biosecurity practice before and after training compared to students. Behaviour change is most likely to occur when participants consider

the training useful or necessary which in turn motivates their behaviour. Training is also dependent on the ability to use the skills whilst working, in comparison to education which focuses on increasing knowledge and awareness (Grossman and Salas 2011). Sometimes individuals reportedly fail to apply, or transfer their learning to the work environment (Grossman and Burke-Smalley 2018). We therefore argue that professionals reported high biosecurity practice compared to students as they could transfer the training to their job (Blume et al. 2019).

Training methods such as e-Learning have been introduced to try to reinforce and improve standards for good biosecurity in the field. Our study shows that the objectives of the e-Learning were met; awareness and risk perception increased as well as an improvement in reported biosecurity behaviour, with these changes evident 6 months post-training. However, Velada et al. (2007) argue that if people do not use their new skills for a while they are likely to forget them before being able to apply them. In the context of human resource management, Wexley and Latham (2002) found that whilst around 40 per cent of training content was transferred immediately, it fell to 25% after 6 months and a further 15% after 1 year. Therefore, we recommend that participants should take advantage of the freely available and flexible *Better Biosecurity e-Learning course*, and repeat the course annually in order to increase retention, sustain motivation and maintain a high level of awareness and behaviour in the future (Lauzier and Mercier 2018). In addition to this, training should be coupled with support structures that encourage a desired behaviour and barriers should be addressed for engaging in this behaviour (e.g. cleaning facilities should be made available to encourage biosecurity practice) (Heimlich and Ardoin 2008).

Methods to prevent the risk of introduction and spread are central to effective implementation of relevant legislation (e.g. CBD, Marine Strategy Framework Directive and the EU IAS Regulation) and/or policy (e.g. the GBNNS Strategy for Great Britain). This study demonstrates that e-Learning is an effective tool to increase personal awareness of IAS and effect changes in behaviour to aid in reducing the risk of introduction/spread. e-Learning is not a panacea and cannot be viewed as a one size fits all answer to all. Ideally e-Learning should be used as part of a suite of methods such as education, training and policy creation, that aid in the implementation of national and international goals for the more effective management of IAS.

6.6 References

- Ajzen I. 1991. The theory of planned behaviour. *Organ Behav Hum Decis Process* 50:179–211. doi: 10.1016/0749-5978(91)90020-T
- Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD. 2015. Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biol Invasions* 17:2287–2297. doi: 10.1007/s10530-015-0875-6
- Arkorful N, Abaidoo V. 2014. The role of e-Learning, advantages and disadvantages of its adoption in higher education. *Int J Educ Res* 2:398–410
- Azeiteiro UM, Bacelar-Nicolau P, Caetano FJP, Caeiro S. 2015. Education for sustainable development through e-Learning in higher education: experiences from Portugal. *J Clean Prod* 106:308–319. doi: 10.1016/j.jclepro.2014.11.056
- Bacelar-Nicolau P, Caeiro S, Martinho AP, et al. 2009. E-Learning for the environment The Universidade Aberta (Portuguese Open Distance University) experience in the environmental sciences post-graduate courses. *Int J Sustain High Educ* 10:354–367. doi: 10.1108/14676370910990701
- Blume BD, Kevin Ford J, Surface EA, Olenick J. 2019. A dynamic model of training transfer. *Hum Resour Manag Rev* 29:270–283. doi: 10.1016/j.hrmr.2017.11.004
- Bouhnik D, Marcus T. 2006. Interaction in distance-learning courses. *J Am Soc Inf Sci Technol* 57:299–305. doi: 10.1002/asi.20277
- Burke LA, Hutchins HM. 2007. Training Transfer: An Integrative Literature Review. *Hum Resour Dev Rev* 6:263–296. doi: 10.1177/1534484307303035
- Corral-Verdugo V. 1997. Dual “realities” of conservation behaviour: Self-reports vs observations of re-use and recycling behaviour. *J Environ Psychol* 17:135–145. doi: 10.1006/jevp.1997.0048
- Crawley M. 2007. *The R book*. Wiley, Chichester
- Curtis GJ, Gouldthorp B, Thomas EF, et al. 2013. Online Academic-integrity Mastery Training May Improve Students’ Awareness of, and Attitudes toward, Plagiarism. *Psychol Learn Teach* 12:282–289. doi: 10.2304/plat.2013.12.3.282

- Defra. 2018. Survey of Attitudes, Knowledge and Behaviour in Relation to Non-native Species. Shropshire; UK
- Estévez RA, Anderson CB, Pizarro JC, Burgman MA. 2015. Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conserv Biol* 29:19–30. doi: 10.1111/cobi.12359
- Gilpin-Jackson Y, Bushe GR. 2007. Leadership Development Training Transfer: A Case Study Of Post-Training Determinants. *J Manag Dev* 26:980–1004. doi: 10.1108/02621710710833423
- Goodwin D, Raffin M, Jeffrey P, Smith HM. 2018. Informing public attitudes to non-potable water reuse e The impact of message framing. *Water Research* 145: 125-135. doi: 10.1016/j.watres.2018.08.006
- Grossman R, Burke-Smalley LA. 2018. Context-dependent accountability strategies to improve the transfer of training: A proposed theoretical model and research propositions. *Hum Resour Manag Rev* 28:234–247. doi: 10.1016/j.hrmr.2017.08.001
- Grossman R, Salas E. 2011. The transfer of training: what really matters. *Int J Train Dev* 15:103–121. doi: 10.1111/j.1468-2419.2011.00373.x
- Harrington SS, Walker BL. 2009. The Effects of Computer-Based Fire Safety Training on the Knowledge, Attitudes, and Practices of Caregivers. *J Contin Educ Nurs* 40:79–86. doi: 10.3928/00220124-20090201-07
- Heimlich JE, Ardoin NM. 2008. Understanding behaviour to understand behaviour change: a literature review. *Environ Educ Res* 14:215–237. doi: 10.1080/13504620802148881
- Hulme PE. 2009. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *J Appl Ecol* 46:10–18. doi: 10.1111/j.1365-2664.2008.01600.x
- Hulme PE, Brundu G, Carboni M, et al. 2017. Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *J Appl Ecol* 55:92–98. doi: 10.1111/1365-2664.12953
- Hungerford HR, Volk TL. 1990. Changing Learner Behaviour through Environmental Education. *J Environ Educ* 21:8–21. doi: 10.1080/00958964.1990.10753743

Hutchins HM, Burke LA . 2007. Identifying trainers' knowledge of training transfer research findings - closing the gap between research and practice. SSRN. doi: 10.1111/j.1468-2419.2007.00288.x

Karanci AN, Aksit B, Dirik G. 2006. Impact of a Community Disaster Awareness Training Program in Turkey: Does It Influence Hazard-Related Cognitions and Preparedness Behaviours. *Soc Behav Personal an Int J* 33:243–258. doi: 10.2224/sbp.2005.33.3.243

Kettunen M, Genovesi P, Gollasch S, et al. 2009. Technical support to EU strategy on invasive alien species (IAS) - Assessment of the impacts of IAS in Europe and the EU (final module report for the European Commission). Brussels, Belgium

Kirkwood A, Price L. 2014. Technology-enhanced learning and teaching in higher education: what is “enhanced” and how do we know? A critical literature review. *Learn Media Technol* 39:6–36. doi: 10.1080/17439884.2013.770404

Lauzier M, Mercier G. 2018. The effect of error orientation, motivation to learn, and social support on training transfer intentions: A moderated mediation model. *Can J Adm Sci* 35:419–428. doi: 10.1002/cjas.1429

Liaw S-S. 2008. Investigating students' perceived satisfaction, behavioural intention, and effectiveness of e-Learning: A case study of the Blackboard system. *Comput Educ* 51:864–873. doi: 10.1016/j.compedu.2007.09.005

Liaw S-S, Huang H-M, Chen G-D. 2007. Surveying instructor and learner attitudes toward e-Learning. *Comput Educ* 49:1066–1080. doi: 10.1016/j.compedu.2006.01.001

Lim H, Lee SG, Nam K. 2007. Validating e-Learning factors affecting training effectiveness. *Int J Inf Manage* 27:22–35. doi: 10.1016/j.ijinfomgt.2006.08.002

Marler JH, Liang X, Dulebohn JH. 2006. Training and effective employee information technology use. *J Manage* 32:721–743. doi: 10.1177/0149206306292388

McDonald F. 2014. Developing an Integrated Conceptual Framework of Pro-Environmental Behaviour in the Workplace through Synthesis of the Current Literature. *Adm Sci* 4:276–303. doi: 10.3390/admsci4030276

McKenzie-Mohr D, Schultz PW. 2014. Choosing effective behaviour change tools. *Soc Mar Q* 20:35–46. doi: 10.1177/1524500413519257

Michie S, Stralen MM Van, West R. 2011. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement Sci* 6:42. doi: 10.1186/1748-5908-6-42

Noesgaard SS, Ørngreen R. 2015. The Effectiveness of E-Learning : An Explorative and Integrative Review of the Definitions, Methodologies and Factors that Promote e-Learning Effectiveness. *Electron J e- Learn* 13:278–290

O'Connor RE, Bord RJ, Fisher A. 1999. Risk perceptions, General Environmental Beliefs, and Willingness to Address Climate Change. *Risk Anal* 19:461–471. doi: 10.1111/j.1539-6924.1999.tb00421.x

Perrings C, Dehnen-Schmutz K, Touza J, Williamson M. 2005. How to manage biological invasions under globalization. *Trends Ecol Evol* 20:212–215. doi: 10.1016/j.tree.2005.02.011

Perron GM, Côté RP, Duffy JF. 2006. Improving environmental awareness training in business. *J Clean Prod* 14:551–562. doi: 10.1016/j.jclepro.2005.07.006

R Core Team. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.r-project.org/>. Accessed 23 Mar 2019

Rothlisberger JD, Chadderton WL, McNulty J, Lodge DM. 2010. Aquatic Invasive Species Transport via Trailered Boats: What is Being Moved, Who is Moving it, and What Can Be Done. *Fisheries* 35:121–132. doi: 10.1577/1548-8446-35.3.121

Salas E, Wilson KA, Priest HA, Guthrie JW. 2006. Design, Delivery, and Evaluation of Training Systems. In: *Handbook of Human Factors and Ergonomics*. John Wiley and Sons, Florida, pp 472–512

Saul WC, Roy HE, Booy O, et al. 2017. Assessing patterns in introduction pathways of alien species by linking major invasion databases. *J Appl Ecol* 54:657–669. doi: 10.1111/1365-2664.12819

Sebire M, Rimmer G, Hicks R, et al. 2018. A preliminary investigation into biosecurity treatments to manage the invasive killer shrimp (*Dikerogammarus villosus*). *Manag Biol Invasions* 9:101–113. doi: 10.3391/mbi.2018.9.2.04

Shannon C, Quinn CH, Stebbing PD, et al. 2018a. The practical application of hot water to reduce the introduction and spread of aquatic invasive alien species. *Manag Biol Invasions* 9:417–423. doi: 10.3391/mbi.2018.9.4.05

Shannon C, Quinn CH, Sutcliffe C, et al. 2018b. Exploring knowledge, perception of risk and biosecurity practices among researchers in the UK: a quantitative survey. *Biol Invasions* 20:399–411. doi: 10.1007/s10530-018-1837-6

Shaw L, Dingle P, Annandale D. 1999. Implementation of Environmental Training Programmes. *Eco-Management Audit* 6:140–147. doi: 10.1002/(SICI)1099-0925(199909)6:3<140::AID-EMA108>3.0.CO;2-K

Simberloff D, Martin J-L, Genovesi P, et al. 2013. Impacts of biological invasions: What's what and the way forward. *Trends Ecol Evol* 28:58–66. doi: 10.1016/j.tree.2012.07.013

Varela-Candamio L, Novo-Corti I, García-Álvarez MT. 2018. The importance of environmental education in the determinants of green behaviour: A meta-analysis approach. *J Clean Prod* 170:1565–1578. doi: 10.1016/j.jclepro.2017.09.214

Velada R, Caetano A, Michel JW, et al. 2007. The Effects of Training Design, Individual Characteristics and Work Environment on Transfer of Training. *Int J Train Dev* 11:282–294. doi: 10.1111/j.1468-2419.2007.00286.x

Wachinger G, Renn O, Begg C, Kuhlicke C. 2013. The risk perception paradox-implications for governance and communication of natural hazards. *Risk Anal* 33:1049–1065. doi: 10.1111/j.1539-6924.2012.01942.x

Wexley KN, Latham GP. 2002. *Developing and Training Human Resources in Organizations*, 3rd Editio. Pearson, Toronto

Williams F, Eschen R, Harris A, et al. 2010. *The Economic Cost of Invasive Non-Native Species on Great Britain*. Oxford, UK

Chapter 7: Discussion and conclusion

7.1 Thesis aim

The primary research aim for this thesis was to understand the effectiveness of existing IAS interventions designed to change specified biosecurity behaviour patterns. This thesis applied an interdisciplinary approach and draws on methods and approaches from a combination of biological, social and political science. The thesis used Ajzen's Theory of Planned Behaviour (1991) to provide a framework for examining human dimensions (such as attitudes, knowledge and risk perceptions) and perceived behavioural control regarding behaviours that prevent the spread of IAS. Human dimensions (such as a person's attitude) can shape and determine an individual's intention to behave. Behaviour change interventions (information, campaigns, policy tools etc) are designed to change specified behaviour patterns by targeting single or multiple human dimensions.

Section 7.2 revisits each of the research objectives, draws out the key findings from the thesis chapters. Section 7.3 discusses how my research helps to help to understand what determines behaviour in the case of IAS, and discusses how interventions are used/could be used to encourage behaviour change in the future. Section 7.4 highlights recommendations for policy and practice, Section 7.5 identifies future areas for research and finally, Section 7.6 provides a summary of the contributions to this field of study.

7.2 Revisiting the research objectives

This thesis has made a range of contributions not just to the improvement of biosecurity procedures themselves (Chapter 5), but also to our understanding of the effectiveness of behaviour change interventions such as policy instruments (Chapter 4), training (Chapter 6) and campaigns (Chapter 2). The main findings of these Chapters and future policy and research recommendations can be found below in Table 7.1. The insights gained from each Chapter and how they are interlinked are discussed in Section 7.3.

Methods to prevent the introduction and spread of IAS are increasingly being recognised as the most cost effective means of reducing the impacts of IAS (Dunn and Hatcher 2015; Cook et al. 2016) and are central to the EU Regulation and the Invasive Non-Native Species Strategy for Great Britain. Biosecurity measures to reduce the introduction and/or spread can involve simple practices such as employing cleaning measures (Anderson et al. 2015b; Dunn and Hatcher 2015), therefore biosecurity is key to slowing the introduction and spread of IAS. In 2015, the UK Department for Environment, Food and Rural Affairs (Defra) launched the

biosecurity campaign Check Clean Dry which aimed to reduce the risk of accidental introduction and spread of aquatic IAS by encouraging biosecurity best practice among water users (e.g. anglers and recreational boaters). The campaign encourages people to check, clean and dry all equipment and clothing thoroughly to kill or remove any organisms that have the potential to hitchhike to new locations. Chapter 2 of this thesis explored the individual human dimensions of IAS management, including factors such as knowledge, risk perception, experience and reported behaviour. Chapter 2 focused on field researchers who are an important group of stakeholders who undertake activities in field that could potentially facilitate the spread of IAS. Individual dimensions such as risk perceptions, are particularly important to study because they are influenced by attitudes, and knowledge and experience and can help predict an individuals' behavioural intentions (Ajzen, 1991; O'Connor et al. 1999; Bugden and Stedman 2019). In this chapter, I investigated researchers' perceptions of risk in relation to their field activities and whether risk perceptions influenced behaviour, which was an important requirement to determine how dimensions influence behavioural change according to Ajzen's theory. A quantitative online survey revealed that overall awareness of biosecurity risk was fairly low, and only 35% of all respondents considered their field activities to pose some risk in terms of spreading IAS. This chapter highlighted how dimensions such as knowledge (from disciplinary area) seemed to have no impact on an individual's risk perception and reported behaviour (although it was associated with actual behaviour). On the other hand, experience of IAS and awareness of IAS campaigns increased an individuals' perception of risk, however there remained a disconnect between reported and actual biosecurity practices. The findings suggest that whilst awareness and risk perceptions often determine behavioural intention, there still remains a lack of understanding about what constitutes good biosecurity practice, and a gap between what people think they do and what they actually do. These findings suggest that behaviour change interventions must be instruction-oriented, and include directed training on specific skills for biosecurity practice, as previous experience of IAS in the field is an important dimension for behavioural change. Interventions such as information campaigns and training should be specific as to what behaviours should be undertaken, including specific things to check for, using hot water for cleaning, and ensuring individuals are drying equipment for a sufficient period of time.

The marine environment is particularly at risk from intentional and unintentional introduction and spread of IAS, as IAS are able to hitchhike on ships, in cargo and on recreational equipment. Once introduced and established, IAS are difficult to control or eradicate, particularly in the marine environment (Katsanevakis et al. 2013; Tidbury et al. 2016). This highlights the importance of preventing introduction and spread of IAS from occurring in the

marine environment; biosecurity is therefore an important tool to slow the spread of IAS. Interventions such as international, regional and national policy instruments have been implemented to address the impact of IAS on the environment, economy and society. Having a coherent policy framework at an international and national level is key to the success of managing the existing and future impacts of IAS in the marine environment and managing the key pathways such as shipping, recreational boating and aquaculture. Chapter 3 explored the coherence of marine biosecurity legislation (as an intervention tool) for IAS at an international and national scale. Policy instruments set standards of what is acceptable behaviour for target groups and work on group dimensions to influence norms and a persons' intention to behave (Ajzen 1991). Both the Bern Convention and Convention on Biological Diversity were consistent with European and national legislation that had been created in response. There was positive interaction between the two conventions, and between the conventions and European and national legislation. The EU IAS Regulation can be directly applied in the UK without being transposed into national legislation. Under the EU IAS Regulation, it is a requirement for management measures to be put in place for widespread IAS. In October 2019, the IAS (Enforcement and Permitting) Order will come into effect and it is imperative that given the UK is about to leave the EU, existing and future legislation must be in accord with previous EU law. It is possible that the UK could end up with a Regulation that does not reflect the ambitions of the EU IAS Regulation; this could potentially create conflict between states and management priorities. The Ballast Water Management Convention has also not yet been transposed into either European or national legislation, which has resulted in a lack of interaction between the Convention aims and other legislation. To address a lack of IAS legislation for the marine environment, there had been a recent shift to use voluntary instruments to address biosecurity of IAS in the marine environment. Both voluntary and legislative instruments should be coherent as any conflicts between these two instruments could potentially weaken the overall effort to establish and maintain biosecurity and achieve behaviour change. This chapter highlighted the potential for policy instruments in changing behaviours of stakeholders, by targeting certain user groups which attempt to increase intention through perceived behavioural control of a certain behaviour (Ajzen 1999).

In Chapter 3, the discussion focused on how policy instruments as interventions set standards of what is acceptable behaviour for target groups, with the goal to work on the group level to influence norms which would eventually increase intention to behave. Identifying and addressing conflicting legislation and incoherent policies, is likely help to avoid conflict on the ground. Therefore, in the following chapter, I explored the relationship between policy and behaviour empirically in order to understand how these policy instruments attempt to change

behaviour through establishing rules or principles through laws or voluntary agreements that target certain activities within the aquatic environment. Knowledge, attitudes and motivations of stakeholders in response to policy instruments can help determine whether these instruments are effective at encouraging positive behaviour change, and if these behaviours are effective at reducing the risk from IAS. Chapter 4 therefore investigated the effectiveness of existing policy instruments as interventions for behaviour change. Using semi-structured interviews, the chapter explored the human dimensions such as knowledge, attitudes and motivations of two stakeholder groups in the marine environment and identified any conflicting advice, which may act as a barrier to intention and perceived behavioural control (according to the Theory of Planned Behaviour). Two of the key pathways for introduction and spread of IAS in the marine environment are aquaculture and recreational boating. Using these two activity groups as case studies, this chapter found that both groups were motivated by different factors. Motivations to undertake biosecurity within the shellfish industry were driven by economic incentives, and penalties for disease control which were a direct result of legislation (Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species). In contrast, there were few regulatory policy instruments to drive IAS biosecurity within the recreational boating sector, which instead relied heavily on voluntary instruments to motivate stakeholders and encourage behaviour change; however, behaviour change was restricted by lack of infrastructure and enforcement. Where regulations and penalties cannot be enforced, voluntary instruments are likely to be more effective in raising awareness, however there are still many barriers to achieving behaviour change. Mainly these include conflicting advice such as voluntary instruments encouraging boaters to clean equipment after use but a lack of infrastructure available to recreational boaters to actually clean equipment. Policy makers should avoid assuming that all policy instruments will directly influence behaviour and instead governments should invest in infrastructure to 'nudge' individuals into socially desirable behaviours which should encourage behaviour as a social norm within a community.

In an attempt to address issues around perceived behavioural control as a result from recent qualitative research conducted by Sutcliffe et al. (2018), which highlights that implementation time can often be a barrier to adoption of biosecurity practices; chapter 5 focussed on increasing perceived behavioural control by improving and refining the 'Clean' advice from the *Check Clean Dry* campaign. Perceived behavioural control refers to people's perceptions of their ability to perform a given behaviour (Prinbeck et al. 2011). Methods to reduce the introduction and spread of IAS are key to reducing the economic, environmental and social impacts of IAS. IAS propagules can be moved around accidentally on clothing and equipment

used in agriculture, transport, trade and recreation (Dunn and Hatcher 2015). Campaigns to slow the spread of aquatic IAS encourage water users to check, clean and dry their equipment and clothes, using hot water during the cleaning process where feasible. The UK Check Clean Dry biosecurity campaign recommends immersion in hot water (45°C) for 15 minutes. Chapter 5 refined the advice from the campaign and tested the efficacy of hot water treatment in actual conditions, with a view to reduce the recommended time to clean equipment while still preventing spread. Immersion for the recommended 15 minutes at 45°C (as suggested by the Great Britain Non-Native Species Secretariat (GBNNS)) caused complete mortality of both animal species as well as one *Crassula helmsii* (New Zealand Pigmyweed), but only 40% mortality of *Myriophyllum aquaticum* (parrots feather). Mortality of plants was higher at higher temperatures. To achieve high mortality of IAS propagules my findings suggest that for practical application in the field, equipment should be immersed in water at 50°C for a minimum of 5 minutes. Interventions such as hot water guidance should be simple, consistent and safe in order to increase adoption to achieve behaviour change. Chapter 5 proposes new shorter times that should encourage uptake of biosecurity (addressing time as a barrier to biosecurity) at safe temperatures (to avoid scalding) and in line with the World Health Organisation guidelines which recommends water should be no less than 50°C to minimise the risk of Legionella bacteria in water. The results also increase reliability of this advice by providing more realistic conditions to the field, and illustrate that these recommendations are effective in the field as well as laboratory conditions. Whilst information is utilised as an intervention for behaviour change which focuses on increasing human dimensions such as knowledge, awareness and supportive attitudes for biosecurity, this chapter reinforces the importance of refining advice and not assuming that information directly relates to behaviour change. This chapter most importantly attempts to increase perceived behavioural control (in accordance with Ajzen's Theory of Planned Behaviour 1991) by reducing the time it takes to practice biosecurity which attempts to increase intention to behave.

Training can support campaigns or work independently by targeting a specific audience to change behaviours. Whilst education focuses more on increasing knowledge, environmental training focuses on developing the necessary skills to address the issue and therefore achieve behaviour change through increasing perceived behavioural control an increase likelihood of intention (Michie et al. 2011). Assuming that the acquisition of knowledge, change in attitudes and the development of skills through training will lead to improved performance (Salas et al. 2006). e-Learning courses have been designed to support the UK's Check Clean Dry campaign by raising awareness among stakeholders and targeting behaviours that pose a risk of accidentally spreading IAS in the marine, freshwater and terrestrial environment. The GBNNS

host e-Learning platforms on their website used by government and stakeholders such as anglers, boaters, environmental practitioners and site workers. Field researchers are also an important group of stakeholders that undertake activities in the aquatic and terrestrial environment and could act as vectors for spread of IAS. Despite e-Learning training investment, the effectiveness of e-Learning in relation to increasing awareness and reported behaviour has yet to be looked at in the context of IAS and biosecurity. Chapter 6 evaluated the effectiveness of e-Learning as an intervention to increase awareness, risk perception and encourage behaviour change among field researchers in relation to IAS. Participants were surveyed before and 6 months after taking the Better Biosecurity e-Learning course designed by the University of Leeds, Cefas, Environment Agency and the GBNNSS (https://openeducation.blackboard.com/mooc-catalog/courseDetails/view?course_id= 1189 1). As expected, awareness of IAS and self-reported biosecurity behaviour increased after e-Learning among both professionals and students. Similarly, e-Learning also led to an increase in reported cleaning practices, with higher levels of biosecurity cleaning amongst professionals after undertaking the e-Learning. Chapter 6 argues that higher awareness and cleaning practices amongst professionals is likely to reflect their familiarity with the issues of IAS and day to day activities in the field which reinforces similar results from Chapter 2 which stress that familiarity and experience are important dimensions for achieving behaviour change (where Chapter 2 argued that knowledge alone was not enough to change behaviours). Our results suggest that e-Learning can be an effective intervention tool to raise awareness and encourage behaviour change among field researchers in an attempt to reduce the risk of accidental introduction and spread of IAS. However, e-Learning should be used as part of a suite of methods such as education, in person training and policy creation, that aid in the implementation of national and international goals for the more effective management of IAS. Finally, training courses such as e-Learning or in person training should be evaluated in order to establish the effectiveness and impact in light of the objectives set. These results can be used and shared to establish an evidence based case for training in the future.

Table 7.1 Thesis Chapter summary of research objectives, justification, key findings and future recommendations.

Chapter	Objective	Justification for the Chapter	Methodology	Key findings	Recommendations for policy and practice
2	a) to investigate the impact of academic discipline, exposure to IAS and information campaigns (i.e. knowledge) on risk perception and biosecurity practice; and b) to explore the impact of field experience and activity on risk perceptions and biosecurity practice. The aim of this study was to investigate researchers' perceptions of risk in relation to their field activities and whether risk perceptions influenced behaviour.	Researchers represent an important group of stakeholders who undertake activities in the field that could potentially facilitate the spread of IAS.	Quantitative Online surveys Descriptive and statistical analysis	Only 35% of all respondents considered their field activities to pose some risk in terms of spreading IAS. Higher risk perception was found in those who undertook high risk activities or where IAS were known/expected to be present. However, whilst respondents with experience of IAS were more likely to report consciously employing biosecurity in the field, this did not translate into better actual biosecurity practices. Awareness of biosecurity campaigns did in fact increase perception of risk, perceived and actual biosecurity behaviour. However, there remains a disconnect between reported and actual biosecurity practices, including a lack of	These findings should be used to improve behaviour change interventions such as instruction-oriented campaigns, and help create directed training on specific skills for biosecurity practice. I recommend that campaigns and training should be designed for specific target groups in order to identify certain behaviours that should be undertaken. The type of biosecurity measures including specific things to check for, using hot water for cleaning, and ensuring individuals are drying equipment for a sufficient period of time should be relevant and targeted using examples for each stakeholder group in order to address the gap between reported and actual behaviour.

3	a) to investigate the consistency and, b) to explore the interaction of biosecurity policies at international and national levels and c) to identify gaps and limitations in existing marine non-native species policy and their implications for implementation in England and Wales.	Prevention measures such as biosecurity are linked to policies and legislative drivers that attempt to implement measures to address the issues and mitigate the impacts of non-native species in the marine environment. Policy is a collection of different instruments used by government to pursue a desired outcome; these instruments attempt to form a coherent strategy to achieve the outcome. Having a coherent policy framework at an international and national level is key to the success of managing the existing and future impacts of non-native species in the marine environment.	Policy analysis - consistency and interaction	I found positive vertical consistency from the three Conventions in relation to aims and terminology. I also found positive vertical interaction. I was unable to analyse the consistency of the BWM Convention as it is yet to be transposed into European and National law, although there was a positive interaction of the BWM Convention with most other policy documents. Some evidence of a lack of interaction between newer sector specific European and national policy and environmental policy.	In order to successfully manage IAS in the marine environment, implementation measures such as policy instruments (both voluntary and legislative) should be coherent as any failure in the chain could potentially weaken the overall effort to establish and maintain biosecurity and achieve behaviour change. I recommend that there is an opportunity to introduce a Biosecurity Act similar to New Zealand in order to further help protect the economy, environment and human health and to manage and reduce the risk that IAS can pose to the UK.
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4	(1) to reveal motivations for undertaking biosecurity and understand whether this is as a result of policy instruments or other factors (2) to understand what extent the current actions undertaken are achieving the goals of good biosecurity practice.	To determine the effectiveness of existing policy and policy instruments on behaviours within the marine environment.	Qualitative Interviews Grounded theory	Participants from the recreational boating sector were much more likely to be motivated by social norms than policy instruments but behaviour change was restricted by lack of infrastructure and enforcement. In contrast, participants from the shellfish industry were heavily regulated (in relation to shellfish disease) and motivations were driven by economic incentives and penalties. However, the shellfish industry also relied on social norms such as the shared expectation that everyone within the industry would implement good biosecurity.	I recommend that there should be investment from the government in infrastructure for stakeholders to undertake biosecurity as well as investment into creating voluntary guidance which can often sit on the shelf (policy makers should avoid assuming that all policy instruments will directly influence behaviour). Visible infrastructure such as wash down stations, posters should 'nudge' individuals into socially desirable behaviours which should encourage behaviour as a social norm within a community.
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5	(a) to determine whether a shorter immersion time can result in high mortality of IAS propagules at the recommended 45°C and (b) to investigate whether higher temperatures can be combined with shorter treatment times to induce high mortality of IAS propagules.	The UK <i>Check Clean Dry</i> campaign encourages people to check, clean and dry all equipment and clothing thoroughly to kill or remove any organisms that have the potential to survive while attached to equipment and be transported to a new location. The use of hot water (45°C for 15 minutes) has been identified as a technique globally to support the “Clean” process within the <i>Check, Clean, Dry</i> campaign. However, research suggests that 15 minutes may be too long to ask people to wait for their equipment to soak and may be difficult to incorporate into their working practices. Reducing the time taken to undertake biosecurity and increasing practicality may increase the adoption of good biosecurity practices.	Laboratory experiment Quantitative statistical analysis	For both invasive animal species, 100% mortality was achieved at all temperature and time treatments. However, plant mortality was affected by both temperature and time, with higher mortality resulting from higher temperatures and exposure times. Immersion for the recommended 15 mins at 45°C caused complete mortality of <i>Crassula helmsii</i> , but only 40% mortality of <i>Myriophyllum aquaticum</i> . Immersion in water at 50 °C or higher led to 100% mortality for <i>Crassula helmsii</i> and 90% mortality for <i>Myriophyllum aquatium</i> at shorter treatment durations of 5 or 10 mins. In addition, immersion in water at 60°C caused 100% mortality after only 1 minute exposure. To ensure adoption and application of biosecurity practices, guidance should be simple, consistent and safe.	I propose new shorter times that should encourage uptake of biosecurity (addressing time as a barrier to biosecurity) at safe temperatures and in line with the World Health Organisation guidelines. The results also increase reliability of this advice and illustrate that these recommendations are effective in the field as well as laboratory conditions. Advice should be updated to include options of 50°C for a minimum of 5 minutes.
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6	<p>By surveying individuals before and after e-learning, I aim to investigate the effectiveness of e-Learning training on awareness of IAS and/or biosecurity campaigns, risk perception of field activities accidentally spreading IAS, and on an individuals' self-reported cleaning and self-reported biosecurity practices.</p>	<p>Online e-Learning is increasingly being used to provide environmental training. Since 2010, e-Learning training has been designed to increase awareness around IAS and biosecurity and encourage pro-environmental behaviours among stakeholders. We present the first study of the effectiveness of e-Learning in influencing the awareness of IAS and biosecurity behaviours.</p>	<p>Quantitative Online pre and post surveys Descriptive and statistical analysis</p>	<p>Awareness of IAS and self-reported biosecurity behaviour increased after e-Learning among students and professionals. Students had a lower awareness of IAS than professionals before training (20% of students vs 60% of professionals), but after training students showed a greater increase in awareness which led to similar levels of awareness post-training (81%). Prior to training, risk perception was also lower amongst students than professionals (33% of students and 59% of professionals were aware of the risk that their activities posed to the accidental spread of IAS). There was no change in risk perception amongst professionals after training, however training led to a doubling of risk perception in students. E-Learning also led to an increase in reported</p>	<p>e-Learning should be used as part of a suite of methods such as education, training and policy creation, that aid in the implementation of national and international goals for the more effective management of IAS. Any investment into e-Learning should be targeted at specific stakeholder groups, using focused and clear examples and be regularly updated in order to increase effectiveness of increasing awareness, changing attitudes and encouraging changes in behaviour.</p>
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				<p>biosecurity behaviour and cleaning practices, with higher levels of biosecurity cleaning amongst professionals.</p> <p>The higher awareness and better biosecurity amongst professionals is likely to reflect their familiarity with the issues of IAS and day to day activities in the field.</p>	
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7.3 Behaviour and behaviour change

Biosecurity is important to slow the spread of IAS. Biosecurity policies aim to change human behaviour in an attempt to reduce the risk of IAS introduction and spread. This thesis aims to examine the effect of individual and group factors in more detail in relation to biosecurity, and evaluate the potential for interventions to change behaviours. This thesis used Ajzen's Theory of Planned Behaviour (1991) to provide a conceptual framework to explore the different factors that are understood to influence an individuals' behaviour (human dimensions, perceived behavioural control and intention), and to understand how existing interventions attempt to change behaviour by influencing those factors. The following sections discuss how individual and group dimensions (taken from the Theory of Planned Behaviour (Ajzen 1991)) were used to understand different factors that influence behaviour and how interventions attempt to change behaviours through these factors. Finally, the last section looks at how perceived behavioural control can be a good indication of intention to perform the desired behaviour and how interventions should focus on improving perceived behavioural control.

Policies and legislative drivers are interventions that attempt to mitigate the spread and impacts of IAS through setting standards of what is acceptable behaviour on the highest level (global, regional, national) rather than targeted on a national or local level. Any conflicts between policies may reduce the effectiveness of the instruments in achieving behaviour change. The policy analysis in Chapter 3 found some evidence of a lack of interaction between newer pathway/sector specific European and national policy, and more targeted environmental policy. The analysis in Chapter 3 was limited to legislative policy but did recognise that existing voluntary instruments were also used to target the behaviours of stakeholders. Voluntary instruments such as codes of conduct can be instrumental to awareness raising, increasing stakeholder involvement, leverage/dissemination of best practices, supplementing existing regulations or filling a regulatory gap (Hulme et al. 2017). Voluntary instruments have been shown to increase the acceptability of regulations through increasing awareness and risk perceptions (Humair et al. 2014). Voluntary instruments including those focusing on sector specific activities (zoological gardens and aquaria, recreational boating, recreational fishing etc) can represent a valid incentive to pilot innovative approaches, possibly supported by governments, to contribute to their overarching biodiversity conservation goals. Voluntary instruments can therefore play an important role to encourage behaviour change (e.g. through awareness raising) to prevent the introduction and spread of IAS. Building on this potential, Chapter 4 evaluated the effectiveness of these marine policy instruments (regulatory and voluntary) on the ground and found that when voluntary instruments were heavily relied on, individuals were often restricted by lack of infrastructure

and enforcement, which suggests that these instruments are ineffective in isolation. This suggests that voluntary instruments should complement regulatory instruments, this has been found elsewhere (Genovesi et al. 2015). Chapter 4 also highlighted areas of conflict between voluntary advice and existing legislation. The combination of regulatory and voluntary instruments therefore presents challenges to the coherence of IAS policy. Combining regulatory and voluntary instruments is a challenge, but the use of voluntary instruments is increasing because of the inadequacy of top-down measures (Tollington et al. 2015; Crowley et al. 2017). Therefore, policy makers must grapple with this challenge and make sure that the combination of regulatory, voluntary instruments do not conflict, and any issues are identified and removed. Having a coherent policy framework of both voluntary and legislative instrument at an international and national level is key to the success of managing the existing and future impacts of IAS in the marine environment. It may be necessary to measure the effectiveness of these instruments in relation to behaviour change to help policy makers understand what drives and motivates stakeholders to change behaviours in relation to IAS.

Results from Chapter 2 suggested that individual dimensions such as awareness of biosecurity campaigns (including *Check Clean Dry*) did increase perception of risk and perceived and actual biosecurity behaviour. However there remains a disconnect between reported and actual biosecurity practices, including a lack of understanding about what constitutes good biosecurity practice. To address this disconnect and to support the delivery of the *Check Clean Dry* campaign, interventions such as e-Learning have been introduced by the GBNNSS which target various stakeholder groups (for example field researchers). The *Better Biosecurity* e-Learning course was introduced in 2015 to target the activities carried out by field researchers with the aim to not only increase awareness, but to increase knowledge of practical skills to encourage better biosecurity practice. Risk perceptions and reported behaviours were measured in Chapter 6 to determine the effectiveness of the *Better Biosecurity* e-learning course and the effectiveness of training on behaviour. Reported behaviours gathered within this Chapter are an indication of transfer; transfer is the application of the newly acquired knowledge and skills (Weisweiler et al. 2013). The results from the e-Learning course indicated that individual dimensions such as risk perceptions and experience were the main factors predicting environmental behaviour. The combination of experience and risk is increasingly important for biosecurity and IAS management as experience can influence a persons' perception of risk which can ultimately determine their decision to act (or not). These results can also be applied to other activities that pose a risk to the accidental spread of IAS such as angling, recreational boating; as individuals undertaking these recreational activities may also be familiar with a

particular location/environment and the activity undertaken. If governments and businesses continue to invest in interventions such as training, training should be repeated by the individuals in order to maintain learning retention; this has also been recognised elsewhere in the literature (Velada et al. 2007). Training should also be coupled with application, and therefore businesses should target relevant individuals that are able to apply the training in the field, otherwise knowledge and skills that have been gained during the training can be lost (Velada et al. 2007). Training platforms should also be updated regularly to display new information/ technologies supported by science (e.g effectiveness of hot water for 'cleaning'), to consider new relevant laws and policies and to remain fresh and relevant, online courses need to be continually revised and improved (Hai-Jew 2010). Finally, the effectiveness of these training tools should be measured in relation to behaviour change, as this is often the primary aim of many training intervention tools.

Perceived behavioural control is also an important factor for increasing intention and changing behaviours. The extent to which a person feels capable and has confidence in their ability to perform the desired behaviour plays an important role in intentions and actual behaviour. In a study exploring the uptake of preventative behaviours among stakeholders, Prinbeck et al. (2011) identified two barriers to perceived behavioural control, the first was the lack of specific and clear information. To address this barrier, Governments have used campaigns and additional guidance. To support the *Check Clean Dry* campaign (and to provide more information on *how* to clean equipment), additional guidance has been created which includes advice on using hot water to clean equipment and drying equipment for 24 hours before using it again. In an attempt to make the desired behaviour of biosecurity easier by reducing the time it takes for biosecurity, this thesis demonstrated that immersion of equipment in water at 50°C for a minimum of 5 minutes can achieve high mortality of IAS propagules. Interventions such as hot water guidance must be clear, concise and practical in order to increase perceived behavioural control. Looking to the future, the *Check Clean Dry* campaign has recently been extended to the activities within the marine environment. The advice that complements and supports the campaign must therefore also be relevant and specific to these activities. However, there is no 'one size fits all' approach to biosecurity and so investment and efforts should be made to produce specific advice for each activity and environment so that is easy to follow. Governments should work with stakeholders to create advice that is context specific, rather than creating advice that is not achievable and met with many barriers. For example, results from both Chapter 3 and 4 highlighted issues with advice to recreational boaters about cleaning boats in the water, where this would actually be an offence under the Marine and

Coastal Access Act 2009 to deposit substances in the sea (especially with the risk of containing IAS).

In addition to a lack of clear guidance and information, the second barrier to perceived behavioural control identified by Prinbeck et al. (2011) was a lack of infrastructure changes available to individuals in order to change behaviour. In the case of biosecurity, often individuals are willing to undertake cleaning measures however, they simply lack the infrastructure and facilities to do this. Results from Chapter 3 also suggested that there was a lack of infrastructure available to individuals within the recreational boating sector mainly due to the economic costs of implementation. Therefore, in addition to creating advice, governments should continue to work with sectors (such as trade, leisure and transport) to ensure that infrastructure is available in order for individual to carry out biosecurity practice. For example, it may be beneficial to highlight high risk entry points for recreational water users and target wash down stations with prompts and signs to encourage water users to use these facilities. The visibility of carrying out biosecurity can also help to improve subjective norms where individuals may be more likely to carry out a behaviour if they are encouraged by others and see others in their social group performing the desired behaviour. Since biosecurity is a visible behaviour there is potential for the action of biosecurity to become acceptable within a community and sustained through social interactions (Rivis and Sheeran 2003; Ham et al. 2015; Nyborg et al. 2016).

Chapter 4 looked at the relationship between policy instruments and motivation to change behaviours and found that whilst individuals were encouraged to undertake biosecurity through the use of policy instruments (legislative and voluntary), subjective norms (mainly social norms) played an important role in determining behaviour. Social norms refer to the perception of other people's opinions on how the individual should behave (Prinbeck et al. 2011). For example, individuals from the shellfish industry were encouraged by the combination of legislation for disease control together with social norms which were shared within social networks. The small size of the shellfish industry increased connectivity between individuals, which allowed social norms to play an important role. On the other hand, the recreational boating sector relied heavily on voluntary instruments, but behaviour was constrained by situational, financial and political factors and due to the size of the industry and limited connectivity, social norms played less of a role. A key challenge is to identify and tap into existing social networks that may be able to spread knowledge about biosecurity within the recreational boating sector, and to stimulate new exchanges and networks where links are undeveloped (e.g. between different scales or between social groups that do not typically interact with one another). Social media may also play an important role to promote social

norms within the recreational boating sector, this can allow stakeholders with similar interests in recreational boating to connect rapidly and with ease. In this way, social media may be a powerful tool to target and connect larger more disparate groups with a common interest (e.g. recreational boaters), and to promote biosecurity behaviour among these groups. Due to the large size of the recreational boating sector (as well as other recreational activities) and the limited connected networks, social media may help to bridge the gap (Reed and Curzon 2015).

7.4 Recommendations for policy and practice

7.4.1 Creation of activity specific campaigns and advice

Campaigns and training should be designed for specific target groups in order to identify certain behaviours that should be undertaken. The *Check Clean Dry* campaign can also be applied to other water users and stakeholder groups but should not assume that individuals know *how* to do biosecurity. The type of biosecurity measures including specific actions such as using hot water for cleaning and drying equipment for a sufficient period of time should be made relevant for each stakeholder group, and include more detail as to how to perform biosecurity. This will help to bridge the gap between reported and actual behaviour being able to visually see the action should help to increase uptake. For example any advice given to recreational boaters, but clearly indicate where and how boaters can clean down equipment, and give illustrative examples. It should also be made clear if and where there are any conflicts and areas where boaters should not deposit substances but alternative direction should be given.

7.4.2 Future consistency of policy instruments

The UK government recognises that IAS pose a constant threat to the UK's ecology and economy and that ensuring effective biosecurity measures are in place is therefore of great and lasting importance. However much of the UK's biosecurity currently depends upon cooperation with the EU. As the UK is set to leave the EU in 2019, this will create challenges for policy but there are also some opportunities for national measures (e.g. tailoring lists of restricted species to better reflect the risks posed to the UK, or increasing checks at ports and airports). Brexit therefore provides an opportunity for the Government to consider fundamentally altering its approach to managing biosecurity, moving away from a system based on a list of restricted items (which does not protect against unknown risks) and towards a unified biosecurity policy across all sectors. It is a requirement under the EU Regulation for management measures to be put in place for widespread IAS. In October 2019, the IAS (Enforcement and Permitting) Order

2019 will be implemented in order to tighten rules around releasing IAS which threaten the UK environment and to tackle future IAS. The effectiveness of this Act is currently unknown, however policy makers should make sure that there are no conflicts between the new Act and existing environmental, social or economic policy, as any conflicts can reduce the effectiveness of policy on the ground. In addition to this, following Australia and New Zealand, the UK should consider creating a Biosecurity Act, which can be an effective approach to maintain biosecurity on an island, in combination with biosecurity campaigns. Leaving the EU could therefore offer the UK the opportunity to improve its biosecurity.

7.4.3 Future investment in infrastructure

In order to increase the likelihood of uptake of biosecurity, the UK Government should invest more money into infrastructure for stakeholders to undertake biosecurity rather than creating voluntary guidance that is often left to sit on a shelf (as highlighted in Chapter 4). Having visible infrastructure available will help to 'nudge' individuals into socially desirable behaviours which should encourage behaviour as a social norm within a community. Investing in infrastructure will not only address practical barriers to biosecurity but could play an important role in increasing trust between the general public and government. Stakeholders (regulators, scientists, authorities etc) should work together to highlight and prioritise high risk hot spot sites to implement washdown facilities. Whilst the creation of voluntary guidance has been somewhat successful, it is limited in its effectiveness to create behaviour change. Therefore, investment should be made into infrastructure to complement existing voluntary guidance.

7.4.4 Annual retraining and updated e-Learning training

Individuals that pose a risk to the accidental spread of IAS (e.g. recreational water users, practitioners, field workers) should complete training annually. This will guard against familiarity which can reduce an individuals' risk perception. In addition to this, any investment into e-Learning should be targeted at specific stakeholder groups, using focused and clear examples and be regularly updated in order to increase effectiveness of increasing awareness, changing attitudes and encouraging changes in behaviour. e-Learning courses should also be used as part of a suite of methods such as education, training and policy creation, that aid in the implementation of national and international goals for the more effective management of IAS. e-Learning should also showcase existing areas where washdown stations are implemented in order to make it clear to how equipment should be cleaned. Any training should use real life examples where possible to help individuals relate to their own experiences.

7.5 Future research

7.5.1 Understand what people perceive as a risk

When asking individuals whether they perceive their activities as a risk, we are assuming that an individual is capable of identifying the risk (in particular the potential risk of spreading IAS on equipment for example). It might therefore be beneficial to further our understanding of what individuals consider as risk by asking individuals to identify hazards. There may be a disconnect between what is considered a risk in terms of behaviour and what the individual considers a risk. Perhaps individuals with low perception of risk (do not consider their activities a risk to spreading IAS) are unable to identify the risk hazards. Also, future research should consider whether there is any relationship between risk identification, risk perception and experience/familiarity.

7.5.2 Further analysis of the interaction between newer voluntary instruments and legislative instruments

The combination of regulatory and voluntary instruments presents challenges to the coherence of IAS policy. A combination of regulatory and voluntary instruments are used within the aquatic environment to target the behaviours of stakeholders. In Chapter 4 interviews with stakeholders revealed that there may be conflicts between existing legislation and new voluntary instruments. In order to successfully manage IAS in the marine environment, implementation measures such as policy instruments (both voluntary and legislative) should be coherent as any failure in the chain could potentially weaken the overall effort to establish and maintain biosecurity and achieve behaviour change. There is potential to examine the coherence of voluntary instruments and legislative instruments to identify any conflicts that may impact the effectiveness and uptake.

7.6 Concluding remarks

Biological invasions are identified as one of the greatest threats to biodiversity globally, having negative economic and social impacts which should be accounted for in any management decision (Crowley et al. 2017). Therefore preventing the unintentional introduction and secondary spread of IAS is considered to be a priority to address the impacts that IAS pose (Dunn and Hatcher 2015b). Preventing the unintentional introduction and secondary spread of IAS by managing and limiting the pathways of introduction is therefore the first and most cost effective control measure and can bring huge economic benefits (Simberloff et al. 2013). Preventing unintentional introductions and spread is extremely challenging as it relies on the

identification and cooperation of stakeholders to mitigate the impacts of IAS (Cottier-Cook et al. 2019). Effective biosecurity is a key component of pathway management, which requires changes in behaviour; behaviour change interventions (information, campaigns, policy tools etc) are designed to target and change specified behaviour patterns by targeting individual or multiple human dimensions in order to achieve behaviour change.

In this thesis, I demonstrate that interventions such as policy, campaigns or training should be not assume behaviour change but should be clear as to what they aim to achieve. The UK government should invest in targeted awareness raising instruction campaigns and training interventions to demonstrate appropriate changes in behaviour. New policy instruments to target new and existing pathways of unintentional introduction should be coherent and consistent as well as take into account existing social norms and networks in order to increase the effectiveness of these interventions on behaviour change. To increase intention, especially where there is heavy voluntary reliance, investment should be put into creating wash down stations at high risk and highly populated areas in an attempt to increase the visibility of the behaviour. The evidence collected throughout this PhD thesis will hopefully provide a useful foundation to improve the effectiveness of these interventions.

7.7 References

- Ajzen I. 1991. The theory of planned behaviour. *Organ Behav Hum Decis Process* 50:179–211. doi: 10.1016/0749-5978(91)90020-T
- Anderson LG, Dunn AM, Rosewarne PJ, Stebbing PD. 2015. Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biol Invasions* 17:2287–2297. doi: 10.1007/s10530-015-0875-6
- Bugden D, Stedman R. 2019. A synthetic view of acceptance and engagement with smart meters in the United States. *Energy Res Soc Sci* 47:137–145. doi: 10.1016/j.erss.2018.08.025
- Cook E, Payne R, Macleod A, Brown S. 2016. Marine biosecurity: protecting indigenous marine species. *Res Reports Biodivers Stud* 5:1–14. doi: 10.2147/RRBS.S63402
- Cottier-Cook EJ, Minchin D, Giesler RJ, et al. 2019. Biosecurity implications of the highly invasive carpet sea-squirt *Didemnum vexillum* Kott, 2002 for a protected area of global significance. *Manag Biol Invasions* 10:311–323. doi: 10.3391/mbi.2019. 10.2.07
- Crowley SL, Hinchliffe S, McDonald RA. 2017. Invasive species management will benefit from social impact assessment. *J Appl Ecol* 54:351–357. doi: 10.1111/1365-2664.12817

- Dunn AM, Hatcher MJ .2015. Parasites and biological invasions: Parallels, interactions, and control. *Trends Parasitol* 31:189–199. doi: 10.1016/j.pt.2014.12.003
- Genovesi P, Carboneras C, Vilà M, Walton P. 2015. EU adopts innovative legislation on invasive species: a step towards a global response to biological invasions? *Biol Invasions* 17:1307–1311. doi: 10.1007/s10530-014-0817-8
- Hai-Jew S. 2010. An Instructional Design Approach to Updating an Online Course Curriculum. In: *Educ. Q.* <https://er.educause.edu/articles/2010/12/an-instructional-design-approach-to-updating-an-online-course-curriculum>. Accessed 13 Jul 2019
- Ham M, Jeger M, Ivković AF. 2015. The role of subjective norms in forming the intention to purchase green food. *Econ Res* 28:738–748. doi: 10.1080/1331677X.2015.1083875
- Hulme PE, Brundu G, Carboni M, et al. 2017. Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *J Appl Ecol* 55:92–98. doi: 10.1111/1365-2664.12953
- Humair F, Kueffer C, Siegrist M. 2014. Are non-native plants perceived to be more risky? Factors influencing horticulturists' risk perceptions of ornamental plant species. *PLoS One* 9:e102121. doi: 10.1371/journal.pone.0102121
- Katsanevakis S, Zenetos A, Belchior C, Cardoso AC. 2013. Invading European Seas: Assessing pathways of introduction of marine aliens. *Ocean Coast Manag* 76:64–74. doi: 10.1016/j.ocecoaman.2013.02.024
- Nyborg K, Anderies JM, Dannenberg A, et al. 2016. Social norms as solutions. *Science* (80) 354:42–43. doi: 10.1126/science.aaf8317
- O'Connor RE, Bord RJ, Fisher A. 1999. Risk perceptions, general environmental beliefs, and willingness to address climate change. *Risk Anal* 19:461–471. doi: 10.1023/A:1007004813446
- Prinbeck G, Lach D, Chan S. 2011. Exploring stakeholders' attitudes and beliefs regarding behaviours that prevent the spread of invasive species. *Environ Educ Res* 17:341–352. doi: 10.1080/13504622.2010.542451
- Reed MS, Curzon R. 2015. Stakeholder mapping for the governance of biosecurity: a literature review. *J Integr Environ Sci* 12:15–38. doi: 10.1080/1943815X.2014.975723

Rivis A, Sheeran P. 2003. Descriptive Norms as an Additional Predictor in the Theory of Planned. *Curr Psychol* 22:218–233. doi: 10.1007/s12144-003-1018-2

Simberloff D, Martin J-L, Genovesi P, et al. 2013. Impacts of biological invasions: What's what and the way forward. *Trends Ecol Evol* 28:58–66. doi: 10.1016/j.tree.2012.07.013

Sniehotta FF, Presseau J, Araújo-Soares V. 2014. Time to retire the theory of planned behaviour. *Health Psychol Rev* 8:1–7. doi: 10.1080/17437199.2013.869710

Sutcliffe C, Quinn CH, Shannon C, et al. 2018. Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. *Biol Invasions* 20:399–411. doi: 10.1007/s10530-017-1541-y

Tidbury HJ, Taylor NGH, Copp GH, et al. 2016. Predicting and mapping the risk of introduction of marine non-indigenous species into Great Britain and Ireland. *Biol Invasions* 18:3277–3292. doi: 10.1007/s10530-016-1219-x

Tollington S, Turbé A, Rabitsch W, et al. 2015. Making the EU Legislation on Invasive Species a Conservation Success. *Conserv Lett* 10:112–120. doi: 10.1111/conl.12214

Velada R, Caetano A, Michel JW, et al. 2007. The Effects of Training Design, Individual Characteristics and Work Environment on Transfer of Training. *Int J Train Dev* 11:282–294. doi: 10.1111/j.1468-2419.2007.00286.x

Weisweiler S, Nikitopoulos A, Netzel J, Frey D. 2013. Gaining insight to transfer of training through the lens of social psychology. *Educ Res Rev* 8:14–27. doi: 10.1016/j.edurev.2012.05.006

Appendices

Appendix A: Ethics approval

Performance, Governance and Operations
 Research & Innovation Service
 Charles Thackrah Building
 101 Clarendon Road
 Leeds LS2 9LJ Tel: 0113 343 4873
 Email: ResearchEthics@leeds.ac.uk



UNIVERSITY OF LEEDS

**Biological Sciences Faculty Research Ethics Committee
 University of Leeds**

Caitriona Shannon
 School of Biology
 University of Leeds
 LS2 9JT

8th June 2016

Dear Caitriona

Title of study: **Biosecurity of Invasive Non-Native Species**
Ethics reference: **BIOSCI 15-023, response 3**

I am pleased to inform you that the above research application has been reviewed by the Faculty of Biological Sciences Research Ethics Committee and following receipt of your response to the Committee's comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
BIOSCI 15-023 Committee Provisional 3.doc	1	08/06/16
BIOSCI 15-023 Ethical Review Form NEW.doc	4	08/06/16
BIOSCI 15-023 Survey questions AFTER.pdf	4	08/06/16
BIOSCI 15-023 Survey questions BEFORE.pdf	3	08/06/16
BIOSCI 15-023 Committee Provisional 2.doc	1	11/05/16
BIOSCI 15-023 further info from supervisor.txt (by email)	1	11/05/16
BIOSCI 15-023 questions BEFORE.pdf	1	11/05/16
BIOSCI 15-023 Committee Provisional	1	26/04/16
BIOSCI 15-023 Example participant consent form.doc	2	26/04/16
BIOSCI 15-023 Information sheet semi-structured interview candidates.doc	2	26/04/16
BIOSCI 15-023 BB Quiz.pdf	1	05/04/16
BIOSCI 15-023 bb-pdf.pdf	1	05/04/16
BIOSCI 15-023 Biosecurity Information Slide.ppt	1	05/04/16
BIOSCI 15-023 Good Fieldwork Practice poster 1.pdf	1	05/04/16
BIOSCI 15-023 Good Fieldwork Practice poster 2.pdf	1	05/04/16
BIOSCI 15-023 Risk Assessment Semi-structured Interviews.doc	1	05/04/16
BIOSCI 15-023 Topic Guide.doc	1	05/04/16

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at <http://ris.leeds.ac.uk/EthicsAmendment>.

Please note: You are expected to keep a record of all your approved documentation. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at <http://ris.leeds.ac.uk/EthicsAudits>. We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie

Senior Research Ethics Administrator, Research & Innovation Service

On behalf of Prof Edward White, Chair, [BIOSCI Faculty Research Ethics Committee](#)

CC: Student's supervisor(s)

Appendix B: Risk assessment

Fieldwork Project Details	
Faculty School/Service	Faculty of Biological Sciences / School of Biology
Location of Fieldwork	UK based, mostly within Yorkshire. Exact locations to be confirmed once interviews are confirmed.
Brief description of Fieldwork activity and purpose	
<p>Qualitative data collection using semi structured interviews with a range of Biosecurity stakeholder organisations will be arranged between May 2017 to August 2017. Interviews will investigate Biosecurity knowledge, the impacts of Biosecurity training and barriers to the uptake of Biosecurity practices amongst water users with particular attention to the Check, Clean, Dry campaign. Due to existing relationships with water users, many interviews will take place in the Yorkshire Dales area.</p>	
Organiser Details	Contact details <i>Name, email, telephone</i>
Course Leader	Caitriona Shannon, c.f.shannon1@leeds.ac.uk , 07535039052
	Alison Dunn, a.dunn@leeds.ac.uk , 0113 3432856
Departmental Co-ordinator	<i>Size of Group, lone working, staff, postgraduate, undergraduate</i>
Nature of visit	Researcher will travel to sites by car to interview participants for no more than one hour per participant. Communication will be made prior to visiting.

Hazard Identification <i>Identify all hazards specific to fieldwork trip and activities, describe existing control measures and identify any further measures required.</i>	
HAZARD(S)	CONTROL MEASURES <i>(e.g. alternative work methods, training, supervision, protective equipment)</i>
Nature of the site <i>School, college, university, remote area, laboratory, office, workshop, construction site, farm, etc</i>	<p>Interviews will be undertaken at the angling and canoeing clubs and site visits within the UK. An itinerary will be made once interviewees have been contacted. The interviewer will carry ID identifying them from the University of Leeds and information on the research being undertaken.</p>

<p>Process <i>Operating machinery, electrical equipment, driving vehicles, handling or working with animals etc</i></p>	<p>Interviews will be arranged and travelled to by rented car.</p> <p>During the interviewing process, the researcher will be aware of the local safety arrangements, fire exits and congregation points.</p> <p>The interviewer will keep in contact with the supervisors after each interview for safety reasons.</p>
<p>Transport <i>Mode of transport</i></p>	<p>Interviewee locations will be accessed by car or public transport. The car MOT is up to date and is fully insured for business use. No dangerous goods will be carried.</p>
<p>Equipment <i>manual handling risks, operation of machinery, tools, use of specialist equipment etc</i></p>	<p>The equipment used for the interviews will be either a phone or Dictaphone for recording purposes only. Those taking part in the interview will be aware about the use of recording equipment before the date of the interview and will have consented to its use.</p>
<p>Violence <i>potential for violence (previous incidents etc)</i></p>	<p>There is a very low risk of violence from interviewees. Interviews will not involve any confrontational lines of questioning. The researcher will avoid putting themselves into any insecure situations and will conduct all interviews in the day time and in open areas including offices, making sure a mobile phone is on and close by.</p> <p>The researcher is familiar with the social and professional environment they will be interacting with and will not be working in areas of high crime.</p>

Additional Control Measures

Training

Identify level and extent of information; instruction and training required consider experience of workers

Researcher has prior experience of conducting semi-structured interviews.

Supervision

Identify level of supervision required

e.g. full time, Periodic telephone/radio contact

A mobile phone will be carried in case of emergency.

Other Controls

e.g. background checks for site visits

Most interviews will be conducted at angling clubs/ canoeing and water sport sites and office premises set up by the interviewee and researcher.

Identify Persons at Risk

Individual(s)

medical condition(s), young, inexperienced, disabilities etc

Caitriona Shannon (C.F.Shannon@leeds.ac.uk; 07535039052)

No known medical conditions.

Work Pattern

time and location e.g. shift work, work at night

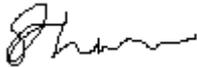
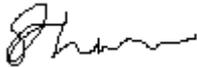
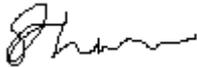
Interviews will be conducted following arrangement with the interviewees via phone and email.

Interviews will be carried out during working hours of 9am-5pm and the working schedule will be known to the principle investigator. Interviews shall be made between May –August 2018. Sites may take up to two hours to get to by public transport or car, therefore adequate food and drink will be carried and available.

Other

e.g. temperature, humidity, confined spaces

n/a

<p><i>This may include more individuals than the fieldwork participants e.g. other employees of partner organisations</i></p>	<p>n/a</p>						
<p><i>Copy of other Organisation's risk assessment attached?</i></p>							
<p>Additional Information</p>							
<p><i>relevant to the one working activity including existing control measures; information instruction and training received, supervision, security, increased lighting, emergency procedures, first aid provision etc.</i></p>	<p>Appropriate clothing will be worn for transport to and from sites and breaks from driving will be taken when necessary.</p>						
<p>Assessment carried out by</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%;">Name:</td> <td>Caitriona Shannon</td> </tr> <tr> <td>Signature :</td> <td></td> </tr> <tr> <td>Date:</td> <td>05/04/2016</td> </tr> </table>	Name:	Caitriona Shannon	Signature :		Date:	05/04/2016
Name:	Caitriona Shannon						
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Date:	05/04/2016						
<p>Names of person(s) involved in Fieldwork <i>N.B: This can take the form of a class register when large group work</i></p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%;">Name:</td> <td></td> </tr> <tr> <td>Signature :</td> <td></td> </tr> <tr> <td>Date:</td> <td></td> </tr> </table>	Name:		Signature :		Date:	
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<p>Name of responsible officer <i>e.g. PI, etc</i></p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%;">Name:</td> <td>Claire Quinn</td> </tr> <tr> <td>Signature :</td> <td></td> </tr> <tr> <td>Date:</td> <td>04/04/2016</td> </tr> </table>	Name:	Claire Quinn	Signature :		Date:	04/04/2016
Name:	Claire Quinn						
Signature :							
Date:	04/04/2016						



Certificate of Completion

This certifies that _____
has completed and passed the Better Biosecurity Course



Signed, Dr Alison Dunn
Faculty of Biological Sciences

6/10/2015

Dated

Appendix C: Field researcher's online survey

Field practices and biosecurity survey

Introductory information

Invasive non-native species (INNS) are plants and animals (vertebrates and invertebrates) that have been accidentally or deliberately introduced to a new area and have the potential to spread causing problems for the environment, economy or human, animal or plant health. The term INNS can also be used to encompass non-native microbes such as bacteria, viruses and fungi that cause problems for human, animal and plant health.

This survey explores the types of field activities that researchers and students do that might inadvertently spread INNS. It will take less than fifteen minutes to complete and may be completed anonymously. We are interested in your responses whether you carry out field activities regularly or only occasionally.

If you decide to take part please click the 'agree' tab below.

Thankyou.

June 2015

*I have read and understood the purpose of this survey and consent for the data I provide to be used in anonymous form for this research project and future research by the University of Leeds. * Required*

Agree

Disagree

Further information: The findings of this survey will be used to complete a report to be submitted to the research funders, NERC (the Natural Environment Research Council), in summer 2015, and will also be disseminated within academic publications within 2015-16. Your data will be anonymised and amalgamated with the data of other participants so that neither you nor your place of work or study will be identifiable in any research outputs. In order to ensure optimum benefits

accrue from this research, it is the policy of the University of Leeds that collected data should be made available in anonymised form to other researchers in future. Should you wish to obtain a summary of the research report and any subsequent publications then please let us know using the contact details given below. By participating in this research you will be assisting in the development of more effective biosecurity recommendations which will help guard against the negative impacts of INNS.

For further information please contact: Dr Claire Quinn (c.h.quinn@leeds.ac.uk), Sustainability Research Institute, University of Leeds, LS2 9JT or Caitriona Shannon, (c.f.shannon@leeds.ac.uk), School of Biology, University of Leeds, LS2 9JT

Demographic details and work/study discipline

Gender

- Male
- Female
- Prefer not to say

Age

- 18-25
- 26-35
- 36-45
- 46-55
- 56-65
- 66 or over
- Prefer not to say

Name of institution (this information will be kept strictly anonymous in any outputs from this research)

Role(s) at institution

- Undergraduate student
- Masters student

- PhD student
- Research assistant
- Post-doctoral researcher
- Lecturer
- Assistant professor/Senior lecturer
- Reader
- Professor
- Technician
- Teaching assistant
- Support staff
- Scientific officer
- Research officer
- Other

If you selected Other, please specify:

Please select the disciplinary area(s) that best describes your study/research/teaching, or select 'other' and provide details

Please select between 1 and 4 answers.

- Agriculture
- Anthropology
- Aquaculture
- Archaeology
- Architecture
- Atmospheric science
- Biology
- Botany

- Climatology
- Conservation
- Earth science
- Ecology
- Engineering
- Entomology
- Environmental science
- Environmental studies
- Forestry
- Glaciology
- Geography
- Geology
- Horticulture
- Hydrology
- Landscape architecture
- Marine biology
- Meteorology
- Mycology
- Oceanography
- Palaeoclimatology
- Palaeontology
- Parasitology
- Remote sensing
- Sedimentology
- Social science
- Sociology
- Soil science
- Surveying
- Sustainability science
- Zoology
- Other

If you selected Other, please specify:

If your work or study is funded please provide the name(s) of your funder(s):

Locations and environments of field activities

Where do you carry out your field activities? (You can select more than one option)

- UK
- Overseas

Which county or counties?

Which country or countries?

Do you take or bring back any samples or equipment?

- Yes
- No

Are there any import/export/quarantine procedures that you follow?

- Yes
- No

Please give a brief description of these procedures

How frequently do you carry out field activities in protected areas (such as Sites of Special Scientific Interest, National Parks or Biosphere Reserves?)

- Always
- Often
- Sometimes
- Rarely
- Never

Please select the environment(s) in which you carry out your field activities

- Woodland
- Freshwater
- Lowland
- Upland
- Marine
- Coastal
- Urban
- Agricultural
- Other

If you selected Other, please specify:

Frequency of field visits

When you are working, teaching or learning in the field roughly how many different sites will you visit in a single week?

- 1-2
- 3-4
- 5-6
- 7-8
- More than 8

Do you typically visit more than one field site in a day?

- Yes
- No

Can you list the locations of the three sites you most recently visited and indicate when each visit took place?

	Location (please provide as much information as you can e.g. map/ GPS co-ordinates, county, country)	Date
First most recently visited	<input type="text"/>	<input type="text"/>  (dd/mm/yyyy)
Second most recently visited	<input type="text"/>	<input type="text"/>  (dd/mm/yyyy)

Third most recently visited	<input data-bbox="592 253 1088 300" type="text"/>	<input data-bbox="1142 226 1289 271" type="text"/> (dd/mm/yyyy) 
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Fieldwork activities

Which activities do you carry out in the field? Please select all that apply.

- Monitoring/ surveying
- Sampling
- Conservation/ habitat management
- Social research methods (interviews/ questionnaires/ focus groups/ participatory methods)
- Supervising others
- Other

Do you ever transport samples between field sites?

- Yes
- No

What do you collect samples of?

If you selected Other, please specify:

Equipment

Do you use equipment in the field?

- Yes
- No

Which item(s) of equipment do you use?

Equipment continued

What does the equipment come into contact with on site?

- Water
- Soil
- Vegetation
- Other

If you selected Other, please specify:

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your equipment before arriving on site?	<input type="checkbox"/>				
...clean your equipment before departing from a site?	<input type="checkbox"/>				
...ensure equipment dries thoroughly in between uses?	<input type="checkbox"/>				
...use the same equipment at more than one site within the same day?	<input type="checkbox"/>				

Please indicate which of the following cleaning methods you employ to clean your equipment before you arrive at a site, before you leave a site, and upon your return from

field activities (tick any that apply).

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine equipment and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

If you soak equipment in hot water, how many minutes do you allow it to soak for?

How do you go about drying your equipment (if at all)?

Transport

How do you normally arrive at your field sites?

- On foot
- By car/ bicycle or other wheeled vehicle
- By boat
- Other

If you selected Other, please specify:

Do you take your vehicle or bicycle off road?

- Always
- Often
- Sometimes
- Rarely
- Never

Transport continued

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your tyres/ wheels or hull before arriving at a field site	<input type="checkbox"/>				
...clean your tyres/ wheels or hull before departing a field site	<input type="checkbox"/>				
...clean your tyres/ wheels or hull after returning from a field site	<input type="checkbox"/>				
...ensure your tyres/ wheels or hull are thoroughly dried in between site visits	<input type="checkbox"/>				

Footwear and outerwear

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your footwear in between site visits?	<input type="checkbox"/>				
...clean your outerwear in between site visits?	<input type="checkbox"/>				

Please indicate which of the following methods you employ to clean your footwear (tick any that apply).

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate which of the following methods you employ to clean your outerwear (tick any that apply).

Please don't select more than 1 answer(s) per row.

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Invasive non-native species

How often do issues related to invasive non-native species come up in relation to your field activities?

- Always
- Often
- Sometimes
- Rarely
- Never

Do you consider your field activities to pose any risk in terms of spreading INNS?

- Yes
- No

Without undertaking any special measures to reduce the risk of spreading INNS, on a scale of 1-5 how much risk do you feel your activities pose?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

	1	2	3	4	5	
Low risk	<input type="checkbox"/>	High risk				

Have you ever carried out field activities in an area where you knew or suspected that INNS were present?

- Yes
- No

Which species?

Did you change anything about how you carried out your field activities as a result of this?

- Yes
 No

Please describe the change(s) you made.

Are you required to produce risk assessments for your field activities?

- Yes
 No

Have you ever mentioned or been asked about INNS in a risk assessment?

- Yes
 No

Did you raise the issue of INNS yourself, or were you asked about INNS by the person evaluating your risk assessment?

- Myself
- Someone else
- Both

Did you specify any procedures within the risk assessment(s) to reduce the risk of spreading INNS?

- Yes
- No

Please describe the procedures you specified

Biosecurity

Are you familiar with any guidance or campaigns on biosecurity?

- Yes
- No

Please specify the guidance or campaign(s) with which you are familiar.

Have you ever undertaken any training on biosecurity?

- Yes
- No

Which organisation provided this training?

When you carry out activities in the field do you consciously employ any biosecurity measures (measures which are specifically aimed at reducing the risk of spreading of INNS)?

- Yes
- No

Biosecurity measures

During field activities do you...

	Always	Often	Sometimes	Rarely	Never
...try to avoid unnecessary contact with INNS?	<input type="checkbox"/>				
...feel confident to challenge the practices of others that you believe present an unacceptable risk of spreading INNS?	<input type="checkbox"/>				

When planning your field activities do you...

	Always	Often	Sometimes	Rarely	Never	Not applicable
...find out whether INNS are known to be present in any of your field sites?	<input type="checkbox"/>					

...take out duplicate sets of equipment in order to use different equipment at different sites to avoid transferring INNS?	<input type="checkbox"/>					
...plan the order in which you visit your sites in order to minimize the risk of spreading INNS?	<input type="checkbox"/>					
...time your field visits in order to avoid higher risk times (e.g. when INNS are seeding or spawning)?	<input type="checkbox"/>					

When supervising others in the field do you...

	Always	Often	Sometimes	Rarely	Never	Not applicable
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...inform those you supervise about the presence or potential presence of INNS?	<input type="checkbox"/>					
...ensure those you supervise undertake biosecurity measures?	<input type="checkbox"/>					

Thank you!

To submit your survey don't forget to click the 'finish' tab at the bottom of this page!

Thank you for taking the time to complete this survey! Your contribution is valuable and will be used to help improve biosecurity guidance for academics and practitioners who undertake field activities. If you would like to provide us with some feedback about this survey please use the box at the bottom of the page. For more information about this research project please contact either Dr Claire Quinn (c.h.quinn@leeds.ac.uk) or Caitriona Shannon (c.f.shannon@leeds.ac.uk).

You are under no obligation to provide us with your contact details. However, if you would be happy to participate in a further research project about biosecurity from autumn 2015 then please provide your name and email address below. Regardless of whether you provide your details, neither you, nor the organisation where you work or study, will be identifiable in any of the research outputs.

Name:

Email address:

If you would like to make any comments about this survey please do so here:

Appendix D: Consistency matrix

Policy consistency										Relevant conventions
Category	Aims of policy	Terminology	Terminology	Primary interests	Economic	Social	Trade	Transit		Relevant conventions
Code	Aims	Prevention	Invasive	Environmental	Economic, economy, production, cost, finance, income, output	Sustainability, development, health, society, welfare, economy	Trade, economy, transport, deal, agreement, goods, services, business, sdt	Transit, location, air, land, sea, shipping, translocation, vehicle		Bern, CBD, BWM
Search terms	Aims, goal, objectives	Prevention and biosecurity	Non-native, invasive non-native, alien, non-indigenous, introduced	conservation, biodiversity, sustainability, environment, plants, animals, fauna, flora						
The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982	The aims of this Convention are to conserve wild flora and fauna and their natural habitats, especially those species and habitats whose conservation requires the co-operation of several States, and to promote such co-operation.		to study control the introduction of non-native species	Recognising that the conservation of wild flora and fauna should be taken into consideration by the governments in their national goals and programmes, and that international co-operation should be established to protect migratory species in particular	The Contracting Parties shall take requisite measures to maintain the population of wild flora and fauna at, or adapt it to, a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of economic and recreational requirements and the needs of sub-species, varieties or forms at risk locally.	in the interests of public health and safety, air safety or other overriding public interests	the regulation as appropriate of sale, keeping for sale, transport for sale or offering for sale of live and dead wild animals			n/a
The Convention on Biological Diversity (CBD) 1992	three main goals: conservation of biodiversity, sustainable use of biodiversity, fair and equitable sharing of the benefits arising from the use of genetic resources	(b) Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species	(b) Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species	pursued in accordance with its relevant provisions, at the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding.	Acknowledging that substantial investments are required to conserve biological diversity and that there is the expectation of a broad range of environmental, economic and social benefits from those investments, recognising that economic and social development and poverty eradication are the first and overriding priorities of developing countries	Promote environmentally sound and sustainable development in areas adjacent to protected areas with a view to furthering protection of these areas				n/a
Ballast Water Management Convention (BWM) 2017	aims to prevent the spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for the management and control of ship's ballast water and sediments	A Party, individually or jointly with other Parties, may impose on ships additional measures to prevent, reduce, or eliminate the transfer of Harmful Aquatic Organisms and Pathogens through ship's Ballast Water and Sediments.	Invasive Aquatic Species				Under the Convention, all ships in international traffic are required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. All ships will also have to carry a ballast water record book and an international ballast water management certificate.	Under the Convention, all ships in international traffic are required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. All ships will also have to carry a ballast water record book and an international		n/a
Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	the main aim of this Directive being to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, this Directive makes a contribution to the general objective of sustainable development, whereas the maintenance of such biodiversity may in certain cases require the maintenance, or indeed the encouragement, of human activities.	to prevent serious damage, in particular to crops, livestock, forests, fisheries and water and other types of property	Whereas provision should be made for supplementary measures governing the reintroduction of certain native species of fauna and flora and the possible introduction of non-native species	the preservation, protection and improvement of the quality of the environment, including the conservation of natural habitats and of wild fauna and flora, are an essential objective of general interest pursued by the Community.	breeding in captivity of animal species as well as artificial propagation of plant species, under strictly controlled conditions, with a view to reducing the taking of specimens of the wild,	promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, this Directive makes a contribution to the general objective of sustainable development, whereas the maintenance of such biodiversity may in certain cases require the maintenance, or indeed the encouragement, of human activities	Member States shall take the requisite measures to establish a system of strict protection for the animal species listed in Annex IV (a) in their natural range, prohibiting, keeping, transport or sale or exchange, and offering for sale or exchange, of specimens taken from the wild, except for those taken legally before this Directive is implemented.			Bern Convention
Water Framework Directive (WFD) 2000/60/EC	aims at maintaining and improving the aquatic environment in the Community. This purpose is primarily concerned with the quality of the waters concerned. Control of quantity is an ancillary element in securing good water quality and therefore measures on quantity, serving the objective of ensuring good quality, should also be established	all practicable steps should be taken to prevent any further deterioration of the status of waters. With regard to pollution prevention and control, Community water policy should be based on a combined approach using control of pollution at source through the setting of emission limit values and of environmental quality standards		Member States shall ensure the establishment of a register or registers of areas lying within each river basin district which have been designated as requiring special protection under specific Community legislation for the protection of their surface water and groundwater or for the conservation of habitats and species directly depending on water	An effective and coherent water policy must take account of the vulnerability of aquatic ecosystems located near the coast and estuaries or in gulfs or relatively closed seas, as their equilibrium is strongly influenced by the quality of inland waters flowing into them. Protection of water status within river basins will provide economic benefits by contributing towards the protection of fish populations, including coastal fish populations	Further integration of protection and sustainable management of water into other Community policy areas such as energy, transport, agriculture, regional policy and tourism is necessary. This Directive should provide a basis for a continued dialogue and for the development of strategies towards a further integration of policy areas. Environmental quality standard means the concentration of a particular pollutant or group of pollutants in water, sediment or biota which should not be exceeded in order to protect human health and the environment	Further integration of protection and sustainable management of water into other Community policy areas such as energy, transport, agriculture, fisheries, regional policy and tourism is necessary. This Directive should provide a basis for a continued dialogue and for the development of strategies towards a further integration of policy areas.			Bern Convention

<p>Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture</p>	<p>This Regulation establishes a framework governing aquaculture practices in relation to alien and locally absent species to assess and minimise the possible impact of these and any associated non-target species on aquatic habitats and in this manner contribute to the sustainable development of the sector</p>	<p>each Contracting Party is required, as far as possible and as appropriate, to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species. This framework should include procedures for the analysis of the potential risks, the taking of measures based on the prevention and precautionary principles and the adoption of contingency plans where necessary, preventing the escape of non-target specimens or biological material that might survive and subsequently reproduce;</p>	<p>alien species' means (a) a species or subspecies of an aquatic organism occurring outside its known natural range and the area of its natural dispersal potential; (b) polyploid organisms, and fertile artificially hybridised species irrespective of their natural range or dispersal potential; 'locally absent species' means a species or subspecies of an aquatic organism which is locally absent from a zone within its natural range of distribution for biogeographical reasons</p>	<p>Invasive alien species have been identified by one of the key causes of loss of native species and harm to bio-diversity. Under Article 8(b) of the Convention on Biological Diversity (CBD), to which the Community is a Party, each Contracting Party is required, as far as possible and as appropriate, to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species. In particular, the Conference of Parties to the CBD has adopted Decision VI/23 on alien species that threaten ecosystems, habitats or species the annex, to which sets out Guiding Principles for the prevention, introduction and mitigation of impacts of such alien species</p>	<p>Aquaculture has benefited economically from the introduction of alien species and translocation of locally absent species in the past (for example rainbow trout, Pacific oyster and salmon) and the policy objective for the future is to optimise benefits associated with introductions and translocations while at the same time avoiding alteration to ecosystems, preventing negative biological interaction, including genetic change, with indigenous populations and restraining the spread of non-target species and detrimental impacts on natural habitats</p>	<p>This Regulation establishes a framework governing aquaculture practices in relation to alien and locally absent species to assess and minimise the possible impact of these and any associated non-target species on aquatic habitats and in this manner contribute to the sustainable development of the sector.</p>	<p>Upon receipt, all life-stages, tanks, water, shipping containers and equipment in contact with the introduced species, including the transport vehicles, must be handled in such a way as to ensure that there is no escape of the species or associated non-target species from the facility. All shipping and packing material must be deinfected, or burned if burning of the material is authorised.</p>	<p>It should be taken into account that movements of alien or locally absent species to be held in closed aquaculture facilities which are secure and which present a very low risk of escape should not be subject to prior environmental risk assessment (a) measures taken to ensure that no other species (non-target species) accompany the shipment;</p>	<p>CBD</p>
<p>Marine Strategy Framework Directive (MSFD) 2008/56/EC</p>	<p>This Directive should, inter alia, promote the integration of environmental considerations into all relevant policy areas and deliver the environmental pillar of the future maritime policy for the European Union.</p>	<p>preventing further deterioration in the status of the marine waters affected and mitigating the adverse impact within the marine region or subregion concerned</p>	<p>Qualitative descriptors for determining good environmental status(2) Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems</p>	<p>By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration.</p>	<p>Member States across a marine region or subregion should undertake an analysis of the features or characteristics of, and pressures and impacts on, their marine waters. Identifying the predominant pressures and impacts on those waters, and an economic and social analysis of their use and of the cost of degradation of the marine environment.</p>	<p>Programme of measures: Economic incentives management measures which make it in the economic interest of those using the marine ecosystems to act in ways which help to achieve the good environmental status objective</p>	<p>Pressures and impacts/introduction of non-synthetic substances and compounds (e.g. heavy metals, hydrocarbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs)</p>	<p>Bern CBD</p>	
<p>Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS</p>	<p>This Regulation should establish rules to prevent, minimise and mitigate the adverse effects of invasive alien species on biodiversity and related ecosystem services, and on human health and safety as well as to reduce their social and economic impact.</p>	<p>This Regulation should establish rules to prevent, minimise and mitigate the adverse effects of invasive alien species on biodiversity and related ecosystem services, and on human health and safety as well as to reduce their social and economic impact.</p>	<p>alien species' means any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or microorganisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce; (2) 'invasive alien species' means an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services; (3) 'invasive alien species of Union concern' means an invasive alien species whose adverse impact has been deemed such as to require concerted action at Union level pursuant to Article 4(3); (4) 'invasive alien species of Member State concern' means an invasive alien species other than an invasive alien species of Union concern, for which a Member State considers on the basis of scientific evidence that the adverse impact of its release and spread, even where not fully ascertained, is of significance for its territory, or part of it, and requires action at the level of that Member State.</p>	<p>Since the objectives of this Regulation, namely to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread of invasive alien species within the Union,</p>	<p>Furthermore, invasive alien species can also have a significant adverse impact on human health and the economy. Only live specimens, and parts that can reproduce, represent a threat to biodiversity and related ecosystem services, human health or the economy, and therefore, only those should be subject to the restrictions under this Regulation</p>	<p>Regulation should establish rules to prevent, minimise and mitigate the adverse effects of invasive alien species on biodiversity and related ecosystem services, and on human health and safety as well as to reduce their social and economic impact. Management measures should avoid adverse impact on the environment as well as on human health.</p>	<p>The risks such species pose may intensify due to increased global trade, transport, tourism and climate change. When proposing the Union list, the Commission should inform that committee on how it took those criteria into account. The criteria should include a risk assessment pursuant to the applicable provisions under the relevant Agreements of the World Trade Organisation (WTO) on placing trade restrictions on species</p>	<p>It is therefore essential to adopt a ban at Union level on intentionally or negligently bringing into the Union, reproducing, growing, transporting, buying, selling, using, exchanging, keeping and releasing invasive alien species of Union concern in order to ensure that early and consistent action is taken across the Union to avoid detriments of the internal market and to prevent situations where action taken in one Member State is undermined by inaction in another Member State. Permits for (c) transport to and from contained holding is carried out under conditions that exclude escape of the invasive alien species as established by the permit;</p>	<p>CBD</p>
<p>The Wildlife and Countryside Act 1981</p>	<p>An Act to repeal and re-enact with amendments the Protection of Birds Acts 1954 to 1967 and the Conservation of Wild Creatures and Wild Plants Act 1975; to prohibit certain methods of killing or taking wild animals to amend the law relating to protection of certain mammals to restrict the introduction of certain animals and plants; to amend the Endangered Species (Import and Export) Act 1976; to amend the law relating to nature conservation, the countryside and National Parks and to make provision with respect to the Countryside Commission; to amend the law relating to public rights of way; and for connected purposes.</p>	<p>preventing serious damage to livestock, foodstuffs for livestock, crops, vegetables, fruit, growing timber, (22), fisheries or inland waters Section 14(1) of the WCA makes it illegal to release or allow to escape into the wild any animal which is not ordinarily resident in Great Britain and is not a regular visitor to Great Britain in a wild state, or is listed in Schedule 9 to the Act.</p>	<p>The Secretary of State may issue or approve a code of practice relating to— (a) animals which are not ordinarily resident in and are not regular visitors to Great Britain in a wild state, (b) animals or plants included in Schedule 9, or (c) any description of animals or plants mentioned in paragraph (a) or (b). A species control agreement or species control order may relate to— (a) an invasive non-native species of animal or plant, or (b) a species of animal that is no longer normally present in Great Britain. A species is 'non-native' if— (a) it is listed in Part 1 or 2 of Schedule 9, or (b) in the case of a species of animal, it is a species— (i) whose natural range does not include any part of Great Britain, and (ii) which has been introduced into Great Britain or is present in Great Britain because of other human activity, best practice (where permitted) for— (i) keeping animals of any type which are invasive or which are kept at a place from which they may not be put out with the control of any person, (ii) keeping plants of any type which are invasive or which are kept at a place with their native range,</p>	<p>Any reference to an invasive animal or plant, or type of such an animal or plant, is a reference to an animal or plant of any type which if not under the control of a person, would be likely to have a significant adverse impact on— (a) biodiversity, (b) other environmental interests, or (c) social or economic interests.</p>	<p>The appropriate authority shall not grant a licence under subsection (3)(b) unless it is satisfied— (a) that undertaking the conduct authorised by the licence will give rise to, or contribute towards the achievement of, a significant social, economic or environmental benefit, and</p>	<p>In any proceedings under subsection (1)(a) it shall be a defence to show that the article was set in position for the purpose of killing or taking, in the interests of public health, agriculture, forestry, fisheries or nature conservation, any wild animals which could be lawfully killed or taken by those means and that he took all reasonable precautions to prevent injury thereby to wild birds.</p>	<p>any offence under the Control of Trade in Endangered Species (Enforcement) Regulations 1997 (S.I. 1997/177) relating to birds (other than an offence under Regulation 9 of those Regulations). Subject to the provisions of this Part, if any person— (a) offers or exposes for sale, or has in his possession or transports for the purpose of sale, any live wild bird other than a bird included in Part 1 of Schedule 3, or an egg of a wild bird or any part of such an egg, or</p>	<p>Any reference to premises— (a) includes reference to land (including lockfast places and other buildings), movable structures, vehicles, vessels, aircraft and other means of transport; but</p>	<p>Bern Convention</p>

<p>The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017</p>	<p>(a) prevent deterioration of the status of each body of surface water; (b) protect, enhance and restore each body of surface water (other than an artificial or heavily modified water body) with the aim of achieving good ecological status and (subject to paragraph (3)) good surface water chemical status, if not already achieved, by 22nd December 2015; (c) protect and enhance each artificial or heavily modified water body with the aim of achieving good ecological potential and (subject to paragraph (3)) good surface water chemical status, if not already achieved, by 22nd December 2021; (d) aim progressively to reduce pollution from priority substances and aim to cease or phase out emissions, discharges and losses of priority hazardous substances.</p>	<p>(a) prevent deterioration of the status of each body of surface water; (c) prevent or reduce the impact of accidental pollution incidents, such as from floods.</p>		<p>"pollution" means the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment;</p>	<p>"water services" means all services which provide, for households, public institutions or any economic activity— The appropriate authority must undertake an d periodically review and (where appropriate) update, in accordance with Annex III to the WFD (economic analysis), an economic analysis of water use in each river basin district.</p>	<p>A failure to achieve good groundwater means good ecological status or (where relevant) good ecological potential, or to prevent deterioration in the status of a body of surface water or groundwater, is not a breach of the environmental objectives set for it under regulation 12 if— (a) the failure is the result of new sustainable development activities, and (b) the reasons for the modifications or alterations, or for the sustainable development activities, are of overriding public interest.</p>			<p>Bern Convention</p>
<p>The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011</p>	<p>These Regulations implement Council Regulation (EC) No 788/2007 (OJ No L 66, 26.6.2007, p.1) concerning use of alien and locally absent species in aquaculture.</p>		<p>Locally absent species Alien</p>	<p>(1) This regulation applies in relation to the proposed movement of— (a) an Annex IV species; or (b) a locally absent species from within the United Kingdom (2) A person proposing to undertake a movement must notify that proposal to the competent authority in writing.</p>		<p>Notifying movement of Annex IV species or locally absent species</p>	<p>Notifying movement of Annex IV species or locally absent species</p>		<p>CBD</p>
<p>The Conservation of Offshore Marine Habitats and Species Regulations 2017</p>	<p>The Regulations make provision in relation to the offshore marine area, offshore marine installations and certain ships and aircraft. The "offshore marine area" is defined in regulation 2. These Regulations consolidate the Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (S.I. 2007/1642) with subsequent amending instruments, and make minor modifications reflecting changes to related legislation. The instruments being consolidated by these Regulations made, among other things, provision for implementing Council Directive 2009/147/EC on the conservation of wild birds (OJ No. L20, 26.01.2010, p.7.) and Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (OJ No. L206, 22.7.92, p.7) in relation to marine areas where the United Kingdom has jurisdiction beyond its territorial sea.</p>	<p>26. Prevention of deterioration of habitats and disturbance of species. (1) Regulations 40, 42 and 43 do not apply to anything done under and in accordance with the terms of a licence granted by the relevant administration under this paragraph, and— (a) in the interests of preserving public health, public safety or air safety; (b) for the purpose of preventing serious damage to fisheries; (c) for the purpose of protecting flora or fauna; (d) for scientific or educational purposes; or (e) for the purposes of the re-population of an area with, or the re-introduction into an area of, wild birds (including any breeding necessary for those purposes); (e) for the purpose of preventing the spread of disease;</p>	<p>Regulation 54 makes it an offence deliberately to introduce a non-native animal or plant, a person in, or on board a ship in, any relevant part of the waters comprised in the offshore marine area commits an offence if, other than in accordance with paragraph (3), that person deliberately introduces into any part of those waters any live animal or plant of a kind having a natural range that does not include those waters</p>	<p>In relation to the offshore marine area, any competent authority having functions relevant to marine conservation must exercise those functions so as to secure compliance with the requirements of the Habitats Directive and the Wild Birds Directive. An introduction in accordance with this paragraph if— (a) it resulted from a discharge of water carried as ballast and the discharge was necessary for the purpose of protecting the safety of any person or ship; and (b) all reasonably practicable steps were taken— (i) to avoid its occurring in an area where it would give rise to a risk of prejudice to natural habitats within their natural range or a risk of prejudice to wild native flora or fauna (whether in the place of introduction or elsewhere); and (ii) to minimise any risk of such prejudice.</p>	<p>In considering which measures may be appropriate for the purpose of securing or contributing to the objective in paragraph (4), appropriate account must be taken of economic and recreational requirements</p>	<p>(a) in the interests of preserving public health, public safety or air safety. The relevant administration must not grant a licence for any purpose mentioned in paragraph (1) unless satisfied that, as regards that purpose, there is no other satisfactory solution</p>	<p>In considering which measures may be appropriate for the purpose of securing or contributing to the objective in paragraph (4), appropriate account must be taken of economic and recreational requirements a person in, or on board a ship in, any relevant part of the waters comprised in the offshore marine area commits an offence if, other than in accordance with paragraph (3), that person deliberately introduces into any part of those waters any live animal or plant of a kind having a natural range that does not include those waters</p>		<p>Bern Convention</p>
<p>Marine Strategy Regulations 2010</p>	<p>with the aim of attaining good environmental status</p>	<p>prevent and reduce inputs into the marine environment, with a view to phasing out pollution, so as to ensure they do not give rise to any significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea.</p>							<p>CBD Bern Convention</p>

Appendix E: Interaction matrix

		The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982	The Convention on Biological Diversity (CBD) 1992	Ballast Water Management Convention (BWM) 2017
		Conventions		
The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982	Conventions		+	+
The Convention on Biological Diversity (CBD) 1992		+		+
Ballast Water Management Convention (BWM) 2017		+	+	
Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	European law	+	+	/
Water Framework Directive (WFD) 2000/60/EC		+	+	+
Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture		+	+	/
Marine Strategy Framework Directive (MSFD) 2008/56/EC		+	+	+
Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS		+	+	+
The Wildlife and Countryside Act 1981	National law	+	+	/
The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017		+	+	+
The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011		+	+	/
The Conservation of Offshore Marine Habitats and Species Regulations 2017		+	+	+
Marine Strategy Regulations 2010		+	+	+

Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	Water Framework Directive (WFD) 2000/60/EC	Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture	Marine Strategy Framework Directive (MSFD) 2008/56/EC	Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS
European law				
+	+	+	+	+
+	+	+	+	+
/	+	/	+	+
	/	-	/	+
+		-	+	+
+	+		+	+
/	+	+		+
+	+	+	+	
+	/	-	+	+
/	+	+	+	+
-	+	+	+	+
/	+	+	+	+
+	+	+	+	+

The Wildlife and Countryside Act 1981	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017	The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011	The Conservation of Offshore Marine Habitats and Species Regulations 2017	Marine Strategy Regulations 2010
National law				
+	+	+	+	+
+	+	+	+	+
/	+	/	+	
+	/	+	/	+
/	+	+	+	+
-	+	+	/	+
/	+	+	+	+
+	+	+	+	+
	/	+	+	+
/		+	+	+
-	+		+	+
+	+	+		+
+	+	+	+	

Appendix F: Policy table

Scale	Document	General aim(s)	Relevance to IAS	Primary interest(s)
International convention	The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) 1982	The principle aims of the Convention are to ensure conservation and protection of wild plant and animal species and their natural habitats, to increase cooperation between contracting parties, and to regulate the exploitation of those species listed (including migratory species).	The Bern Convention is a binding international legal instrument in the field of nature conservation. The Convention recognises that IAS pose a significant threat to the aims of conserving wild flora and fauna and their natural habitats within Europe and therefore the introduction of IAS must be controlled.	Environmental
	The Convention on Biological Diversity (CBD) 1992	As the first global treaty to provide a legal framework for biodiversity conservation, the Convention established three principle goals. (1) the conservation of biological diversity, (2) the sustainable use of its components, (3) the fair and equitable sharing of the benefits arising from the use of genetic resources.	Article 8(h) of the CBD states that Parties should "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".	Environmental

	Ballast Water Management Convention (BWM) 2017	The principle aim of the BWM Convention is to prevent the spread of harmful aquatic organisms, by establishing standards and procedures for the management and control of ships' ballast water and sediments.	Introduces a global framework to control the transfer of potentially IAS in ships' ballast water.	Environmental Economic Travel Trade
European legislation	Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Habitat Directive)	The principle aim of the Habitats Directive is to promote the maintenance of biodiversity by requiring Member States to take measures to maintain or restore natural habitats and wild species listed on the Annexes to the Directive at a favourable conservation status, introducing robust protection for those habitats and species of European importance.	Article 22 of the Directive requires Member States to "ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated so as not to prejudice natural habitats within their natural range or the wild native fauna and flora and, if they consider it necessary, prohibit such introduction."	Environmental
	Water Framework Directive (WFD) 2000/60/EC	The purpose of the Directive is to establish a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial	Aim to achieve or maintain a good ecological status for European inland, transitional and coastal waters and prevent their further deterioration. Non-native species are one of the significant pressures that could result in a water body failing to meet environmental objectives (such as failing to	Environmental

		ecosystems and wetlands meet 'good status'.	achieve good ecological status).	
	Marine Strategy Framework Directive (MSFD) 2008/56/EC	The MSFD outlines a legislative framework for an ecosystem-based approach to the management of human activities which supports the sustainable use of marine goods and services. The overarching goal of the Directive is to achieve 'Good Environmental Status' (GES) by 2020 across Europe's marine environment.	IAS are considered to prevent good environmental status being achieved. Descriptor 2 states that "Non-indigenous species introduced by human activities are at levels that not adversely alter the ecosystem".	Environmental Social Economic
	Council Regulation (EC) No. 708/2007 concerning the use of alien and locally absent species in aquaculture	The principle aim is to ensure there is adequate protection of aquatic habitats.	Establishes a dedicated framework to assess and minimise the possible impact of alien and locally absent species used in aquaculture in the aquatic environment.	Environmental Economic
	Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of IAS	The principle aim is to set three distinct types of measures which follow an internationally agreed hierarchical approach to combatting IAS: Prevention, Early detection and rapid eradication and Management.	This imposes restrictions on a list of species known as 'species of Union concern', published in Commission Decision. These are species whose potential adverse effects across the European Union are such that concerted action across Europe is required. The list then managed with Member States using risk	Environmental Social Economic

			assessments and scientific evidence.	
National legislation	The Wildlife and Countryside Act 1981	The Wildlife and Countryside Act 1981 is the primary legislation which protects animals, plants and habitats in the UK.	Section 14(1) of the Act makes it illegal to release or allow to escape into the wild any animal which is not ordinarily resident in Great Britain and is not a regular visitor to Great Britain in a wild state or is listed in Schedule 9 to the Act.	Environmental
	The Conservation of Offshore Marine Habitats and Species Regulations 2017	The Conservation of Habitats and Species Regulations 2017 form the legal basis for the implementation of the Habitats and Birds Directives in terrestrial areas and territorial waters out to 12nm in England and Wales (including the inshore marine area) and to a limited extent in Scotland and Northern Ireland.	The regulation makes it an offence to deliberately introduce any live non-native animal or plant which would give rise to a risk of prejudice to natural habitats within their natural range or a risk of prejudice to wild native flora or fauna.	Environmental

	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017	This Regulation transposes the Water Framework Directive into national law in the UK. The Regulations outline the duties of regulators in relation to environmental permitting, abstraction and impoundment of water in order to achieve “good status” (or good ecological potential for artificial or heavily modified water bodies).	Non-native species are one of the significant pressures that could result in a water body failing to meet environmental objectives (such as failing to achieve good ecological status).	Environmental
	Marine Strategy Regulations 2010	This statutory instrument transposes the requirements of the MSFD into UK legislation and requires the UK to take necessary measures to achieve or maintain a good environmental status in the marine environment by 2020.	Achievement of GES will be assessed against eleven descriptors which include descriptor 2: Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems	Environmental
	The Alien and Locally Absent Species in Aquaculture (England and Wales) Regulations 2011	This Regulation implements Council Regulation (EC) 708/2007. It makes provision with respect to permits issued by the competent authority under the Regulation, notifying movement of Annex IV species or locally absent species, environmental risk assessments, contingency plans and monitoring.	Establishes a dedicated framework to assess and minimise the possible impact of alien and locally absent species used in aquaculture in the aquatic environment. A risk assessment is needed to import a new species into the UK or to relocate.	Environmental Economic

Appendix G: Interview information sheet**UNIVERSITY OF LEEDS****Biosecurity strategies for invasive non-native species**

You are being invited to take part in a research project. This information sheet will help you decide whether to participate by explaining why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please get in touch with the researcher using the contact details below if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Invasive species have negative impacts in UK ecosystems with repercussions for biodiversity and environmental and human health. They can be very costly to control. Reducing the spread of invasive species in the UK is therefore widely recognised as extremely important. Biosecurity is a practical measure to prevent the spread of invasive species. **The aim of this research project is to gain a better understanding of biosecurity implementation in the marine environment.**

You are being invited to participate in a semi-structured interview to discuss your opinions and activities in the marine environment. If you agree, you will be interviewed at a place and time convenient to you for about one hour. Interviews will be informal and consist of a mix of open and closed questions. We are keen to hear about your opinions on invasive species, biosecurity practices and policy, so you will be encouraged to raise any additional topics you are interested in discussing. The interview will be recorded so that it can be transcribed. Recordings will be deleted once transcriptions are made and then will be stored securely.

The findings of the research will be used to complete a PhD thesis chapter and will be submitted to the research funders, NERC, by September 2019. Should you wish to obtain a summary of the research report and any subsequent publications please let the researcher know using the contact details given at the bottom of the page. By contributing your time to participate in this research you will help to develop greater understanding of biosecurity practice so that recommendations can be shaped to best reflect the capabilities of stakeholders in the marine environment whilst also reducing the spread of invasive species.

It is up to you to decide whether or not to take part, you will receive no payments for participating but the interviewer will work around your time and schedule. If you do decide to take part you will be given this information sheet to keep (and be asked to sign a consent form) and you can still withdraw at any time before 31st December 2018. You do not have to give a reason. After this date, analysis will begin and you are no longer able to withdraw.

It is our policy to ensure that you remain anonymous during the course of the research and in any outputs that are produced subsequently (such as publications or reports). With permission, the researcher may use direct quotes in publications and other research outputs, and will preserve the anonymity of the information. By agreeing to participate, you agree that your data may be used in future by other researchers in anonymised form.

If you would like further information, please contact: Caitriona Shannon,
(C.F.Shannon1@leeds.ac.uk), School of Biology, University of Leeds, LS2 9JT

You can keep this information sheet and a copy of the accompanying consent form.

Thank you for taking part in this project.

March 2018

Appendix H: Interview consent form



UNIVERSITY OF LEEDS

Consent to take part in marine biosecurity for invasive alien species

Add your initials next to the statement if you agree

I confirm that I have read and understand the information sheet dated April 2018 explaining the above research project and I have had the opportunity to ask questions about the project.	
I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. [If participant wishes to withdraw from the study, the data that has been created will be stored but not used].	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research. I understand that my responses will be kept strictly confidential.	
I understand that other researchers may use my words in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	
I understand that relevant sections of the data collected during the study, may be looked at by auditors from the University of Leeds or from regulatory authorities where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.	
I agree to take part in the above research project and will inform the lead researcher should my contact details change.	

Name of participant	
Participant's signature	
Date	
Caitriona Shannon (c.f.shannon1@leeds.ac.uk)	
Signature	
Date*	

*To be signed and dated in the presence of the participant.

Once this has been signed by all parties the participant should receive a copy of the signed and dated participant consent form, the letter/ information sheet and any other written information provided to the participants. A copy of the signed and dated consent form should be kept with the project's main documents which must be kept in a secure location.

Appendix I: Interview topic guide

About organisation

Introductions

- What is your job role within organisation [dependent on individual]
- What are the activities that are undertaken, by yourself and others (events, individually going out etc)

Awareness of IAS as an organisation

- What are the most common IAS that you come across in the marine environment?
- Are there any IAS that are a future concern?
- How are these current and predicted IAS most likely to be spread around? (animal movement, water source, animal husbandry, farm traffic, large events, equipment etc)
- What are the biggest impacts of these IAS in the marine environment? And do these directly impact you and your organisation activities?
- Is there a concern within your organisation about accidental spread of these IAS through the activities that you undertake?

Objective 2: Investigate biosecurity actions undertaken

- How often do you/others use a/your boat/equipment? Is it used abroad? Where do you go?
- Where do you keep it?
- How do you tend to clean your boat? Does it only get cleaned if it is noticeably dirty?
- Have you ever recognised that your hull is dirty?
- What specific measures do you/others put in place to prevent spreading or introduction IAS? Can you give me examples of scenarios where this advice is carried out? Equipment in place to conduct cleaning? (e.g. in water cleaning, sprays etc)
- Do you use any additional measures such as hot water decontamination, disinfectants?
- Do you feel you have enough resources to do biosecurity?
- Is biosecurity applied all the time, or only for high risk activities? If not all the time, why?
- Is training in biosecurity available to staff and others?
- Where do you get information on biosecurity measures?

and determine whether biosecurity action is a response to policy instruments or to other factors.

- Why do you do biosecurity? E.g. community, looking after the environment, other organisations monitoring you?
- Why might someone not undertake biosecurity? Are there any factors that you think might prevent someone from undertaking biosecurity measures? Obstacles or barriers?
- Is anyone responsible for checking compliance of staff/others who undertake biosecurity?
- What are the consequences for someone not doing biosecurity?
- Do you think biosecurity is taken seriously at all times? Do you feel people would do these activities regardless?

Objective 1: Investigate stakeholder awareness and perceptions of relevant biosecurity policy for England and Wales,

- Are you aware of any policy (legislation?) for England and Wales that is relevant for your activities? OR you mentioned X policy, are you aware of any other policies like this”
- If so, how do they have an impact on what you do?
 1. Wildlife and Countryside Act
 2. Water Framework Directive, Marine Strategy Framework Directive
 3. Alien Species and Aquaculture Regulations
 4. EU IAS Regulation
 5. Ballast water convention
- Are they easy to follow/understand?
- How often are you made aware of relevant legislation/policy?
- Is your organisation aware of and promote following these policies? If not, why do you think not?
- Are there any conflicts between policies that you are aware of or that you feel conflict with the activities you undertake?

and knowledge of the interventions/measures which aim to achieve the objectives of the legislation.

- Are there any financial incentives (grants) available to your organisation to implement biosecurity? If yes, what are they and how do they work?
- If not, do you feel these might be helpful for your organisation to achieve better biosecurity? For example [dependent on activity]
- Does your organisation have its own biosecurity guidance/policy? If yes, please expand on the key objectives, how this was developed, when this was developed, and why this was developed and who it is aimed at, is it voluntary or compulsory.
- Are there any voluntary documents relevant to your organisation activities?
 - GBNNSS Strategy
 - Voluntary guidance – codes of conducts (ballast water, recreational boating)
 - Awareness raising campaign
- [dependent on which] Do you feel the guidance and information is useful? What do you find helpful? What don't you find helpful?
- Are you aware of the check clean dry campaign? Does your organisation know of this campaign? Or use any of the guidance on biosecurity? What do you think of the CCD campaign? Is it easy to follow? If not, why not?

Objective 3: Explore to what extent actions are achieving the goals of policy instruments in creating good biosecurity practice to reduce the risk of spreading/introducing IAS.

- What do you feel is most useful way to encourage people to do biosecurity?
- Whose responsibility do you think it is to ensure that biosecurity measures are in place?
- Do you think more can be done to prevent the spread of IAS in the marine environment? Do you feel your organisation is doing enough?
- Could more be done to impose implications for people who do not do biosecurity?

Appendix J: Evidence of the Theory of Planned Behaviour from both sectors

Table 4.2 Evidence of the Theory of Planned Behaviour from both sectors

Elements of the Theory of Planned Behaviour framework	Shellfish industry	Recreational boating sector
Attitude	Positive attitude towards doing biosecurity for disease. Attitudes towards biosecurity for IAS were less positive, but attitude did not have any impact on intention and behaviour as biosecurity was compulsory due to disease regulation. Attitudes were often positive as a result of the economic and commercial benefits produced from having good biosecurity measures.	Attitudes for biosecurity were positive, however biosecurity for IAS prevention was not considered a major concern as there was still a lack of evidence to suggest that recreational boating is a risk to the accidental spread of IAS. Participants also felt that it was unfair to carry out biosecurity when there were often other activities such as shipping that would also pose a risk but not be practicing biosecurity. Conflicting advice was also having a negative impact on attitudes as participants felt that they were restricted and therefore unsure of how to actually carry out biosecurity in a safe and legal manner.
Subjective norm	Played an important part in the intention to carry out biosecurity, as there was pressure from neighbouring farms and businesses to carry out biosecurity for the greater good and collective action.	Biosecurity was not yet considered to be of great concern to the recreational boating sector, and participants felt that there was yet any social pressure from groups or individuals to carry out biosecurity. This was mainly because biosecurity was not yet compulsory, and where biosecurity was made compulsory at marinas, recreational boaters would often avoid.
Perceived behavioural control	Biosecurity for IAS prevention was considered be easy to perform, as there were existing infrastructure in place as a result from having to perform biosecurity for disease control.	Restricted by lack of infrastructure available to them in order to actually carry out biosecurity. Also restricted by any compulsory reason to perform biosecurity and existing conflict between regulation and voluntary guidance for biosecurity

		which instead of encouraging boaters to perform biosecurity was in fact having a negative impact on attitudes and perceived behavioural control.
Intention	There was a strong intention to carry out biosecurity as it was a regulatory requirement to perform biosecurity. Intention to perform biosecurity was also influenced by the recognised benefits that would come from performing good biosecurity such as commercial reputation and economic reward.	Intention was lacking as participants identified many barriers that prevented them from actually carrying out biosecurity, including the lack of others performing this behaviour and the lack of actual wash down stations. Intention was also lacking as there was no regulatory requirement for doing biosecurity.
Behaviour	Agreement that all shellfish farms would be performing biosecurity. Although behaviour was as a result from disease control rather than voluntary for IAS prevention.	Biosecurity performance was voluntary and therefore not all recreational boaters would actually be performing biosecurity for the reason of IAS. Cleaning boats would only be done for maintenance every 6 months to a year.

Appendix K: Online e-Learning pre-training survey

Field practices and biosecurity pre-training survey

Introductory information

Invasive non-native species (INNS) are plants and animals (vertebrates and invertebrates) that have been accidentally or deliberately introduced to a new area and have the potential to spread causing problems for the environment, economy or human, animal or plant health. The term INNS can also be used to encompass non-native microbes such as bacteria, viruses and fungi that cause problems for human, animal and plant health.

This survey explores the types of field activities that researchers and students do that might inadvertently spread INNS. It will take less than fifteen minutes to complete and may be completed anonymously. We are interested in your responses whether you carry out field activities regularly or only occasionally.

If you decide to take part please click the 'agree' tab below.

Thankyou.

August 2016

*I have read and understood the purpose of this survey and consent for the data I provide to be used in anonymous form for this research project and future research by the University of Leeds. * Required*

Agree

Disagree

Further information: The findings of this survey will be used to complete a report to be submitted to the research funders, NERC (the Natural Environment Research Council), and will also be disseminated within academic publications within 2018-19. Your data will be anonymised and amalgamated with the data of other participants so that you will not be identifiable in any research outputs. In order to ensure optimum benefits accrue from this research, it is the policy of the

University of Leeds that collected data should be made available in anonymised form to other researchers in future. Should you wish to obtain a summary of the research report and any subsequent publications then please let us know using the contact details given below. By participating in this research you will be assisting in the development of more effective biosecurity recommendations which will help guard against the negative impacts of INNS. Participation in this study will not influence/impact on your education or assessments whilst at the University of Leeds. If you do decide to take part you can still withdraw at any time before March 2018. You do not have to give a reason but after this date analysis will begin and you are no longer able to withdraw.

For further information please contact: Dr Claire Quinn (c.h.quinn@leeds.ac.uk), Sustainability Research Institute, University of Leeds, LS2 9JT or Caitriona Shannon, (c.f.shannon@leeds.ac.uk), School of Biology, University of Leeds, LS2 9JT

Demographic details and work/study discipline

Please enter your student/staff ID number.

Gender

- Male
- Female
- Prefer not to say

Age

- 18-25
- 26-35
- 36-45
- 46-55
- 56-65
- 66 or over
- Prefer not to say

Name of faculty or school (this information will be kept strictly anonymous in any outputs from this research)

Role(s) at institution

- Undergraduate student
- Masters student
- PhD student
- Research assistant
- Post-doctoral researcher
- Lecturer
- Assistant professor/Senior lecturer
- Reader
- Professor
- Technician
- Teaching assistant
- Support staff
- Scientific officer
- Research officer
- Other

If you selected Other, please specify:

Study

- Full Time
- Part Time

Please select the disciplinary area(s) that best describes your study/research/teaching, or select 'other' and provide details

Please select between 1 and 4 answers.

- Agriculture
- Anthropology
- Aquaculture
- Archaeology
- Architecture
- Atmospheric science
- Biology
- Botany
- Climatology
- Conservation
- Earth science
- Ecology
- Engineering
- Entomology
- Environmental science
- Environmental studies
- Forestry
- Glaciology
- Geography
- Geology
- Horticulture
- Hydrology
- Landscape architecture
- Marine biology
- Meteorology
- Mycology
- Oceanography
- Palaeoclimatology
- Palaeontology
- Parasitology

- Remote sensing
- Sedimentology
- Social science
- Sociology
- Soil science
- Surveying
- Sustainability science
- Zoology
- Other

If you selected Other, please specify:

Locations and environments of field activities

If you are a first year student and have not yet undertaken any fieldwork, please answer the following sections with future courses and research in mind.

Where do you carry out your field activities? (You can select more than one option)

- UK
- Overseas

Which county or counties?

Which country or countries?

Do you take or bring back any samples or equipment?

- Yes
- No

Are there any import/export/quarantine procedures that you follow?

- Yes
- No

Please give a brief description of these procedures

How frequently do you carry out field activities in protected areas (such as Sites of Special Scientific Interest, National Parks or Biosphere Reserves?)

- Always
- Often
- Sometimes
- Rarely
- Never

Please select the environment(s) in which you carry out your field activities

- Woodland
- Freshwater
- Lowland
- Upland
- Marine
- Coastal
- Urban
- Agricultural
- Other

If you selected Other, please specify:

Frequency of field visits

When you are working, teaching or learning in the field roughly how many different sites will you visit in a single week?

- 0
- 1
- 2-3
- 4-5
- 6-7
- More than 7

Do you typically visit more than one field site in a day?

- Yes
- No

Fieldwork activities

Which activities do you carry out in the field? Please select all that apply.

- Monitoring/ surveying
- Sampling
- Conservation/ habitat management
- Social research methods (interviews/ questionnaires/ focus groups/ participatory methods)
- Supervising others
- Other

Do you ever transport samples between field sites?

- Yes
- No

What do you collect samples of?

If you selected Other, please specify:

Equipment

Do you use equipment in the field?

- Yes
- No

Which item(s) of equipment do you use?

Equipment continued

What does the equipment come into contact with on site?

- Water
- Soil
- Vegetation
- Animals
- Other

If you selected Other, please specify:

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your equipment before arriving on site?	<input type="checkbox"/>				
...clean your equipment before departing from a site?	<input type="checkbox"/>				
...ensure equipment dries thoroughly in between uses?	<input type="checkbox"/>				
...use the same equipment at more than one site within the same day?	<input type="checkbox"/>				

Please indicate which of the following cleaning methods you employ to clean your equipment before you arrive at a site, before you leave a site, and upon your return from

field activities (tick any that apply).

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine equipment and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

If you soak equipment in hot water, how many minutes do you allow it to soak for?

How do you go about drying your equipment (if at all)?

Transport

How do you normally arrive at your field sites?

- On foot
- By car/ bicycle or other wheeled vehicle
- By boat
- Other

If you selected Other, please specify:

Do you take your vehicle or bicycle off road?

- Always
- Often
- Sometimes
- Rarely
- Never

Transport continued

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your tyres/ wheels or hull before arriving at a field site	<input type="checkbox"/>				
...clean your tyres/ wheels or hull before departing a field site	<input type="checkbox"/>				
...clean your tyres/ wheels or hull after returning from a field site	<input type="checkbox"/>				
...ensure your tyres/ wheels or hull are thoroughly dried in between site visits	<input type="checkbox"/>				

Footwear and outerwear

How often do you...

	Always	Often	Sometimes	Rarely	Never
...clean your footwear in between site visits?	<input type="checkbox"/>				
...clean your outerwear in between site visits?	<input type="checkbox"/>				

Please indicate which of the following methods you employ to clean your footwear (tick any that apply).

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please indicate which of the following methods you employ to clean your outerwear (tick any that apply).

Please don't select more than 3 answer(s) per row.

	Before arriving at a field site	Before leaving a field site	Upon returning to your place of work/ study
Examine and pick off any visible biomass by hand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in cold water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rinse in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Soak in hot water	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wash with detergent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Clean with disinfectant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dry thoroughly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Invasive non-native species

How often do issues related to invasive non-native species come up in relation to your field activities?

- Always
- Often
- Sometimes
- Rarely
- Never

Do you consider your field activities to pose any risk in terms of spreading INNS?

- Yes
- No

Without undertaking any special measures to reduce the risk of spreading INNS, on a scale of 1-5 how much risk do you feel your activities pose?

Please don't select more than 1 answer(s) per row.

Please select at least 1 answer(s).

	1	2	3	4	5	
Low risk	<input type="checkbox"/>	High risk				

Have you ever carried out field activities in an area where you knew or suspected that INNS were present?

- Yes
- No

Which species?

Did you change anything about how you carried out your field activities as a result of this?

- Yes
 No

Please describe the change(s) you made.

Are you required to produce risk assessments for your field activities?

- Yes
 No

Have you ever mentioned or been asked about INNS in a risk assessment?

- Yes
 No

Did you raise the issue of INNS yourself, or were you asked about INNS by the person evaluating your risk assessment?

- Myself

- Someone else
- Both

Did you specify any procedures within the risk assessment(s) to reduce the risk of spreading INNS?

- Yes
- No

Please describe the procedures you specified

Biosecurity

Are you familiar with any guidance or campaigns on biosecurity?

- Yes
- No

Please specify the guidance or campaign(s) with which you are familiar.

Have you ever undertaken any training on biosecurity?

- Yes
- No

Which organisation provided this training?

When you carry out activities in the field do you consciously employ any biosecurity measures (measures which are specifically aimed at reducing the risk of spreading of INNS)?

- Yes
- No

Biosecurity measures

During field activities do you...

	Always	Often	Sometimes	Rarely	Never
...try to avoid unnecessary contact with INNS?	<input type="checkbox"/>				
...feel confident to challenge the practices of others that you believe present an unacceptable risk of spreading INNS?	<input type="checkbox"/>				

When planning your field activities do you...

	Always	Often	Sometimes	Rarely	Never	Not applicable
...find out whether INNS are known to be present in any of your field sites?	<input type="checkbox"/>					
...take out duplicate sets of equipment in order to use different equipment at different sites to avoid transferring INNS?	<input type="checkbox"/>					

...plan the order in which you visit your sites in order to minimize the risk of spreading INNS?	<input type="checkbox"/>					
...time your field visits in order to avoid higher risk times (e.g. when INNS are seeding or spawning)?	<input type="checkbox"/>					

When supervising others in the field do you...

	Always	Often	Sometimes	Rarely	Never	Not applicable
...inform those you supervise about the presence or potential presence of INNS?	<input type="checkbox"/>					
...ensure those you supervise undertake biosecurity measures?	<input type="checkbox"/>					

Identification

On a scale of 1-5 (where 1 is not at all confident and 5 is very confident) how confident are you at identifying INNS that are...

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5
...terrestrial animals	<input type="checkbox"/>				
...terrestrial plants	<input type="checkbox"/>				
...aquatic animals	<input type="checkbox"/>				
...aquatic plants	<input type="checkbox"/>				

Thank you!

To submit your survey don't forget to click the 'finish' tab at the bottom of this page!

Thank you for taking the time to complete this survey! Your contribution is valuable and will be used to help improve biosecurity guidance for academics and practitioners who undertake field activities. If you would like to provide us with some feedback about this survey please use the box at the bottom of the page. For more information about this research project please contact either Dr Claire Quinn (c.h.quinn@leeds.ac.uk) or Caitriona Shannon (c.f.shannon@leeds.ac.uk).

You are under no obligation to provide us with your contact details. However, if you would be happy to participate in a further research project about biosecurity from September 2017 then please provide your name and **personal** email address below (if you will no longer be at university in 2017). Regardless of whether you provide your details you will not be identifiable in any of the research outputs.

Name:

Email address:

If you would like to make any comments about this survey please do so here: