INVASIVE ALIEN SPECIES IN THE REPUBLIC OF IRELAND:

POLICY RECOMENDATIONS FOR THEIR MANAGEMENT

REPORT PREPARED FOR THE WATER FORUM

by

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Executive Summary

1. Invasive Alien Species (IAS) have serious global impacts, are increasingly invading Europe, and are of particular concern to Ireland as an island with naïve and often unique native flora and fauna. IAS impacts in the environment include reducing biodiversity, negatively affecting ecological stability, and degrading ecosystem functions and services. IAS also threaten human, animal and plant health.

2. The Republic of Ireland (referred to henceforth as Ireland) already has many IAS and many more are forecast to arrive. There is thus an urgent requirement for policies that lead to actions to prevent new incursions into the island of Ireland, early detection and rapid responses to any new introductions, and effective biosecurity and management of existing IAS.

3. Here, a new economic analysis indicates that, should successful management interventions not be introduced, the costs to Ireland of IAS will rise to €26.5 billion per year by 2030 for all IAS, with aquatic and semi-aquatic IAS alone costing over €3.8 billion per year. These are likely underestimates of current and future IAS costs. Control and eradication of current invaders, and prevention of future ones, should therefore be a priority, as relatively modest timely investment may prevent catastrophic losses and costs in the future.

4. Pathways of IAS into new locations include release, escape, transport stowaways and contaminants; the report identifies critical IAS pathways for Ireland as border porosity, recreational angling and boating, internet sales, garden centres, pet shops and aquarists, deliberate releases due to bans, plus the expansion of aquaculture. Trade will likely result in many new IAS reaching Ireland in the future.

5. Ireland has a plethora of both domestic and EU legislation and governance dealing with IAS, particularly Statutory Instrument 477 and the EU IAS Regulation 1143/2014. The latter requires identification of pathways of IAS introduction and spread, surveillance and monitoring of IAS incursions, with expectations of action to eradicate or manage IAS populations.

6. Mechanisms exist for preventing new IAS and managing existing IAS in Ireland, and there are some success stories. However, few emergency response protocols exist, biosecurity is poorly applied, and management is often ineffective. Examples of good biosecurity practice and a range of options of practical eradication, control and management tool boxes that require further development and implementation. International and national success and failure case studies in respect of IAS issues are also presented.

7. The report highlights the importance of education, awareness and communication in relation to IAS issues among the public, stakeholders and the legislature. Outreach programmes can prevent new incursions and provide early detection and timely management interventions. Such projects need rolling out across Ireland, such as in relevant industries, schools, clubs and environmental groups, with effective communications such as social media, citizen science and workhops. International and national case studies of success and failure in IAS communications are presented.

8. The following key policy recommendations for IAS management in Ireland are proposed:

1. **Establish a suitably resourced, single lead Division that is responsible for Invasive Alien Species management in Ireland, working under the aegis of the National Parks and Wildlife Service (NPWS)**.
2. **Establish an All-Ireland IAS Forum**.
3. **Develop a national Biosecurity Strategy for Ireland.**
4. **Provide appropriate resources, training and support in relation to IAS for our national Customs services at ports/entry points throughout Ireland.**
5. **Produce comprehensive Management Plans for IAS currently in Ireland, along with Contingency Plans for IAS expected to arrive in the future (based on horizon scan exercises)**.
6. **Develop a surveillance programme to regularly monitor water bodies for the presence and status of IAS**.
7. **The new IAS legislation for Ireland that will come into force in 2021 must be implemented and enforced by the responsible agency**.
8. **Develop national IAS education and awareness programmes in Ireland.**
9. **Harness community involvement and support to ensure the long-term sustainability of national and local IAS and biosecurity programmes**.
10. **Significantly increase the level of research and management funding into IAS**.

Introduction and rationale

1.1 General introduction to Invasive Alien Species (IAS)

Globally, IAS are considered as pervasive threats to the environment, native biodiversity and related biosecurity (Ricciardi *et al.* 2013; Dick *et al.* 2017; Kemp *et al.* 2021). IAS negatively impact the ecological stability of invaded habitats and native species, leading to consequent pressures on essential ecosystem functions and services (Simberloff *et al.* 2013; IPBES, 2019; Pyšek *et al.* 2020; Ricciardi *et al.* 2021). It is estimated that, in Europe, 11% of the *c.* 12,000 introduced alien species are invasive, causing significant environmental, economic and social damage (EU 2014). While moderate progress has been made up to the end of 2020, there is no evidence of a slowing down in the number of new IAS introductions and the relevant Aichi target in the Convention on Biological Diversity has only been partially achieved (Secretariate of the Convention on Biological Diversity 2020). Indeed, recent research suggests that Europe is now predicted to receive a further 2,500 IAS by the year 2050 (Seebens *et al.* 2020). Recent global assessments concur that there will be no abatement in the increasing rate of biological invasions in the near future (Seebens *et al.* 2017, 2018, 2019; Pyšek *et al.* 2020). In recent decades, the implementation of IAS management throughout Europe has been fragmented and uncoordinated (Caffrey *et al.* 2014; Piria *et al.* 2017). The Republic of Ireland (henceforth Ireland) is under threat from invasions by a wide range of aquatic and terrestrial species as IAS introduction, establishment and spread continue to rise throughout the region (O'Flynn *et al.* 2014; Lucy *et al.* 2020).

The ecological effects of IAS are often irreversible and, once established, they can be extremely difficult and costly to control and eradicate. Ecological impacts include predation, introduction of parasites and pathogens, extirpation of native species, competition for resources, alteration of ecosystems and dilution of native gene pools. The impacts to biodiversity are significant, with 65 out of 174 critically endangered EU species on the IUCN red list in danger due to the impacts of IAS (Thomas 2012). Furthermore, IAS are the sole or contributing cause of 25% and 33% of plant and animal extinctions, respectively (Blackburn *et al*. 2019).

The control and management of IAS is an urgent issue that warrants immediate and sustained attention. Early detection and rapid response, such as eradication, can prevent IAS becoming established and significantly reduce adverse environmental impacts on potentially infested systems. Most priority or high impact IAS can establish and proliferate very rapidly and to defer control and eradication measures can result in a failure to effectively manage a species once it is established.

The island of Ireland, lying on the western edge of Europe, is fortunate to possess a relative paucity of non-native species that can be deemed to be truly invasive (Lucy *et al.* 2020). However, those introduced species that are established and invasive clearly pose considerable problems for our unique ecosystems, our human, animal and plant health, ecosystem services and the Irish economy (see Section 1.2 for the new economic analysis conducted specifically for this report). A number of high-profile invasive species have become

established in Irish freshwater, marine and terrestrial habitats during the past two decades (Lucy *et al.* 2004, 2005, 2012; Minchin and Sides 2006; Caffrey *et al.* 2008a, 20011a,b, 2018; Sweeney 2009; Hayden and Caffrey 2013; Dick *et al.* 2013) and the majority of IAS issues in Ireland affect aquatic (freshwater and marine) and riparian habitats (Lucy *et al.* 2020). A number of these invasive species have posed and/or continue to pose significant risks to biodiversity and ecosystem function in Ireland. We present summary case studies of some existing IAS in Ireland within this report, illustrating common themes among these species. Furthermore, a list of 204 aquatic and semi-aquatic species introduced into the island of Ireland is presented in Appendix I.

Examples of invasive alien plant species (IAPS) impacts that create significant economic costs include: riparian zone damage causing riverbank erosion and flooding; impeded access to and navigation in water bodies that prevents aquatic recreation; increased cost of land development due to removal of Japanese knotweed; and, risks to public health due to toxic sap of Giant hogweed and subsequent human skin damage (Pejchar and Mooney 2009).

Worryingly, horizon scanning exercises have identified a potential new set of aquatic invaders that could soon reach Great Britain (Gallardo and Aldridge 2013; Roy *et al.* 2014) and by extension and proximity become imminent threats to Ireland. Indeed, a recent horizon scan for IAS for the island of Ireland (Lucy *et al.* 2020) identified, by expert consensus, a number of new IAS that are likely to arrive in Ireland in the next few years; of these, 9 of the top 10, and 25 of the top 40 horizon scan species are known to severely disrupt aquatic ecosystems (see Appendix II). It is, therefore, imperative that IAS governance in Ireland is strengthened among the disparate agencies and stakeholders that are involved in the issue, and the true economic costs of unmanaged *versus* managed IAS is considered in a national strategy.

A recent Irish EPA funded all-Ireland research project on *Prevention, Control and Eradication of Invasive Alien Species* (Lucy *et al.* 2021) identified pressures, informed policy, and developed solutions for some IAS in Ireland. The senior authors of that research now present this extensive report on improving the management of IAS in Ireland, focusing on policy gaps and recommendations. A Policy Brief to accompany this document details proposed changes to governance and policy required in Ireland for management of IAS.

1.2 Economic cost of current and future IAS

Financial costs of IAS relate to a variety of direct and indirect factors, including negative impacts on natural capital and ecosystem services, and the direct costs associated with spread prevention, management of established invasions and maintenance of water utilities impacted by invasions. In financial terms, aquatic and terrestrial invasions incur massive annual economic costs that are set to increase substantially in the next 10 years (Diagne *et al*. 2020). Almost a decade ago, the total IAS costs for Ireland were estimated at €203 million per year (Kelly *et al*. 2013). This figure is likely to be a gross underestimate and thus, with many more new

invasions occuring since then, a new and timely analysis of IAS cost estimates in Ireland is presented in this report.

Despite burgeoning current and future invasion rates of IAS globally (Seebens *et al*. 2017, 2020), and increasing knowledge of the diverse ecological impacts of invasions (Dick *et al*. 2017; Crystal-Ornelas and Lockwood, 2020), economic impacts have remained relatively overlooked and poorly estimated. However, the recently developed InvaCost database (Diagne *et al*. 2020) provides the most up-to-date, comprehensive and standardised compilation of global invasion costs. These costs are recorded across a number of descriptors (>50, including taxonomic group, location, habitat) that enable analyses of invasion costs at different scales (e.g. national economies). In brief, InvaCost is based on a systematic literature search to compile invasion cost entries *via* the Web of Science, Google Scholar and Google search engines, as well as by contacting relevant authorities and stakeholders to obtain invasion cost information (Diagne *et al*. 2020; Angulo *et al*. 2020). InvaCost records these invasion costs in a standard currency (USD) and year (2017) to enable comparison and to account for inflation. For the purposes of invasion costs reported here, the figures are converted to 2017 EUR (×0.885; 2017 World Bank Exchange Rate). The following new and bespoke analyses for Ireland, conducted for this report, are based on the most recent research using the InvaCost database at the Europe-scale (see Haubrock *et al*. 2021).

Across Europe, total invasion costs have been estimated at €116.2 billion for the year 2020 (Haubrock *et al*. 2021), after accounting for time lags in cost reporting (i.e. between cost occurrence and publication). Socio-economic parameters, such as GDP, have been found to be reliable and significant predictors of invasion costs arising from both IAS damages and management (Haubrock *et al*. 2021). When distributing this total among European countries with reported costs based on their GDP (2017 value; World Economic Outlook Database), in 2020 it is estimated that Ireland incurred total invasion costs of €2.1 billion. This is a more than ten-fold increase in the 2013 annual invasion cost estimate for Ireland by Kelly *et al.* (2013).

Haubrock *et al*. (2021) found that aquatic and semi-aquatic invasions accounted for an estimated 14.5% of total invasion costs - where semi-aquatic species are defined as those that characteristically use water for their development, reproduction and/or foraging (e.g. Coypu is a semi-aquatic rodent; Water primrose is a semi-aquatic plant). When distributed among habitat types accordingly, aquatic invasions are projected to have cost €305.5 million in Ireland in 2020.

Based on data from the last 60 years, Haubrock *et al*. (2021) projected at least a 12.6-fold invasion cost increase every ten years across Europe. Considering this rate of increase, total costs of biological invasions could reach €26.5 billion per year by 2030 in Ireland. The share of these costs caused by aquatic and semi-aquatic IAS could increase to over €3.8 billion per year in 2030, should management strategies not become more effective.

When considering types of invasion costs, those arising from resource damages or losses have been found to outweigh management costs three-fold at the Europe-scale (Haubrock *et al*. 2021). Thus, by 2030, if

management investments do not become more efficient and effective, direct damages from aquatic and semi-aquatic IAS could reach €2.9 billion per year, with management costs of *c.* €900 million per year. Furthermore, these costs assume that invasion rates will remain constant, when it is known that they are accelerating through time (Seebens *et al*. 2017, 2020; Bailey *et al*. 2020).

Despite recent syntheses of economic costs (Diagne *et al*. 2020), invasion costs in Ireland and elsewhere are likely massively underestimated, owing to knowledge gaps. In freshwater and marine ecosystems, in particular, damages and losses to resources are difficult to quantify, yet aquatic ecosystems provide vital ecosystem services and are crucial for livelihoods (Darwall *et al*. 2018). Moreover, management expenditures are often neither explicitly reported nor publicly available in Ireland, and indirect costs are often non-market in nature and require unconventional economic valuation methods (e.g. "Revealed Preferences"). Invasion cost reporting in Ireland has thus remained scarce, with the vast majority of costs (98%) reported from a single study (Kelly *et al*. 2013; see Diagne *et al*. 2020).

Overall, very few IAS in Ireland have reported invasion costs. The InvaCost database records costs for only one aquatic invader (Curly waterweed), with the remainder not species-specific (i.e. "Diverse/Unspecified"). Compiling a list of known aquatic and semi-aquatic IAS in Ireland from: (1) the Global Invasive Species Database GISD, (2) National Biodiversity Data Centre Catalogue of Ireland's Non-native Species NBDC, and (3) Minchin (2007), shows that there are currently *c.* 204 aquatic species introduced into Ireland (see Appendix I). There is, thus, an urgent need for documentation of the damage costs of these aquatic IAS, now and in the future, to better inform the resourcing of management actions. Gaining this information is also challenging, as IAS management costs may not always be uniquely identifiable – for example, cleaning fouled pipework in drinking water plant intakes may involve a number of issues including mechanical and hydraulic repairs, and thus the costings may not be sufficiently broken down to reflect the removal of Zebra mussel (*Dreissena polymorpha*) or invasive plants.

Although the results presented in this study are based on assumptions, given the lack of species-specific information, it is highly likely that our estimates are conservative, with greater cost reporting in Ireland required to estimate the "true" cost of biological invasions. In future, as invasions into aquatic systems increase (Bailey *et al*. 2020), there will be an associated rise in economic costs — at least 12.6-fold to €3.8 billion in the year 2030 in Irish aquatic ecosystems, presuming no improved management efficiency. Therefore, further investments in targetted management are urgently needed to reduce current and future costs, particularly given that early-invasion stage management (i.e. biosecurity to prevent introduction and spread) is much more cost-effective than long-term control (Leung *et al*. 2002). Indeed, post-invasion retroactive management has been found to be 25-times more costly that pre-invasion management (Diagne *et al*. 2020). Control and eradication of current invaders, and prevention of future ones, should therefore be a priority, as relatively modest timely investment may prevent catastrophic losses and costs in the future. An ounce of IAS prevention is truly worth a pound of IAS cure!

As a specific example from the top 10 future IAS in Ireland (Lucy *et al*. 2020), we predict the arrival of the Salmon fluke (*Gyrodactylus salaris*), a parasite which can devastate salmon stocks. Globally, the Salmon fluke has caused at least €2.5 billion in economic impacts in recent decades (Cuthbert *et al*. 2021). With the Irish salmon angling industry valued conservatively at €11 million in 2003 (INDECON 2003), and the associated enormous natural capital value of this iconic species, the loss of Atlantic salmon (*Salmo salar*) in Ireland would be a major loss in terms of biodiversity, heritage and economy. Relatively cost efficient, sustained and effective biosecurity would minimise the risk, and thus costs, of this and other invaders arriving in Ireland in the near future.

There is also an economic justification for early detection and rapid response, such as eradication, as demonstrated for the highly invasive Water primrose (*Ludwigia* spp). The cost to control an outbreak of 2.38ha in the UK (1998 to 2010) was £27,320 (or £11,467 per hectare). However, estimates for the eradication of this species in Ireland (2013 estimate) were in the order of £20 million , should the plant have become widespread, that is, if no early detection, rapid response or management programmes were implemented (Kelly *et al.* 2013).

1.3 Pathways for the introduction of IAS to Ireland

As a small island on the edge of Europe, Ireland has experienced fewer invasions by IAS than Great Britain or countries on mainland continental Europe. However, increasing globalisation is accelerating the rate of IAS introductions to Ireland, as evidenced by the fact that many of the most problematic aquatic invasive species present in Ireland today were introduced within the last 20 years (O'Flynn *et al.* 2014). These include species such as *Chelicorophium curvispinum* - discovered in 2003 (Lucy *et al.* 2004), Chub - confirmed in 2005 (Caffrey *et al*. 2008), Curly waterweed - discovered in 2005 (Caffrey and Acevedo 2008; Caffrey *et al*. 2009, 2011b), Chinese mitten crab - discovered in 2006 (Minchin 2006), Bloody-red shrimp - discovered in 2008 (Minchin and Holmes 2008, Dick *et al*. 2013), Water primrose - discovered in 2009 (Caffrey internal report) and the Asian clam – discovered in 2010 (Sweeney 2009; Caffrey *et al*. 2011a; see Appendix I).

The Regulation (EU) 1143/2014 on IAS (EU 2014), hereafter the EU Regulation, defines pathways as the routes and mechanisms of the introduction and spread of IAS. The CBD pathways categorisation, as published in the CBD note (CBD 2014), uses six major pathway types (Release, Escape, Contaminant, Stowaway, Corridor and Unaided), building upon them through the addition of subcategories that separate out the different reasons or ways in which species are either intentionally or unintentionally transported or disperse (Harrower *et al.* 2018). Results from a recent horizon scan of IAS in Ireland indicate that Escape (for terrestrial, freshwater and marine), Transport Stowaway (freshwater and marine) and Transport Contaminant (terrestrial) are the main pathways for the future introduction of IAS into Ireland, with multiple pathways existing for some species (Lucy *et al*. 2020; Figure 1). Although this horizon scan was conducted for both jurisdictions on the island of Ireland,

the predicted pathways identified can be considered for the introduction of IAS solely to Ireland (internationally and *via* the border with Northern Ireland (NI)).

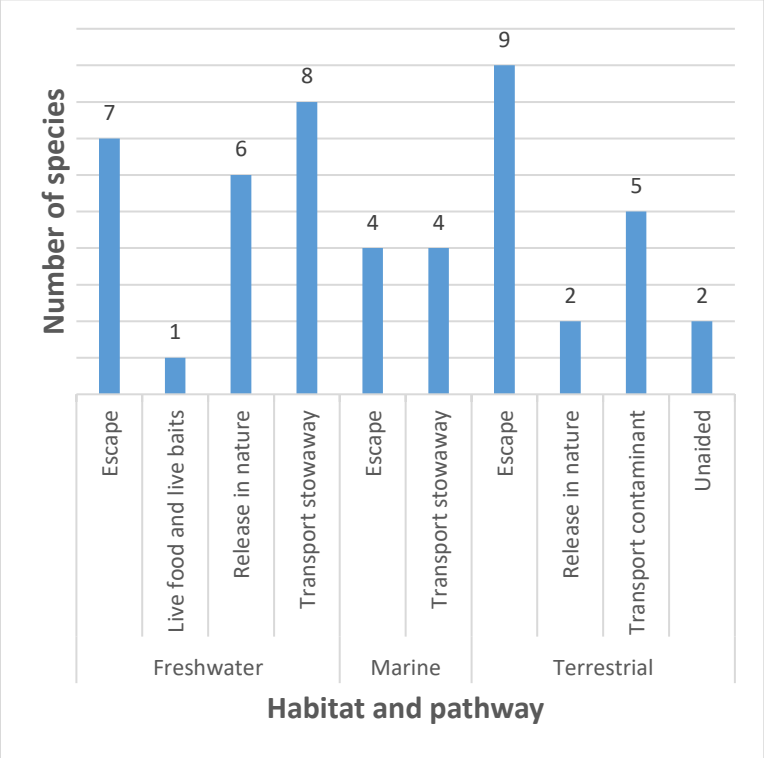

Figure 1: Main pathways for the future introduction of invasive alien species into Ireland (Lucy *et al.* 2021).

Article 13 of the EU Regulation states that Member States (MS) shall, within 18 months of species appearing on the list of Union concern (the Union list), carry out comprehensive analyses of pathways of introduction and spread, and identify the pathways that require priority action. It further states that, within three years of the Union list being adopted, MS must establish and implement one single pathway action plan (PAP) or a set of action plans to address priority pathways. In Ireland, the regulatory agency for IAS, the National Parks and Wildlife Services (NPWS), is currently preparing drafts of two PAPs - for recreational angling and recreational boating. These are two pathways that were considered priority from the pathway analysis study that was undertaken on the listed species of Union concern. These are being drafted with input from relevant government departments, state agencies and representative groups. Final PAPs should be available in Q3 of 2021. It is intended to commence work on a third priority pathway, soil transportation, in 2021.

Pathways of introduction and spread often relate to known recreational, domestic and industrial activities. A comprehensive knowledge of these activities, the relevant pathways, impacts of existing and potential species, and the relevant stakeholders and competent authorities can provide the coherent framework necessary to develop sustainable pathway management.

Below, the authors offer their collective experiences relating to invasion pathways globally, regionally and with particular relevance to the island of Ireland, which influence their expert opinions with regards to likely

pathways of new IAS incursion to Ireland. Our credentials in the sphere of expert opinion and horizon scanning can be perused in Sutherland *et al.* (2008), Caffrey *et al.* (2014); Piria *et al.* (2018); Lucy *et al.* (2020) and Kemp *et al.* (2021).

1.3.1 Pathways that require urgent attention in Ireland

Border Control – Robust legislation, backed by the resources to implement and enforce it, is in place in Ireland and Northern Ireland to effectively halt the introduction of animal and plant pests and diseases into the country. In our experience, however, Ireland's ports are very porous to the introduction of IAS, reflecting the lack of appropriate legislation and, more particularly, resources provided to the Customs authorities, north and south, to target against these harmful invaders. In our own travels in and out of Ireland, we have experienced Customs/biosecurity arrangements that are far below the standards of those in countries such as the USA, Canada, Australia and New Zealand. Several southern African countries are more geared towards IAS prevention at ports than Ireland/Northern Ireland (J. Dick pers. obs.). Two examples follow that illustrate this. In NI, documentation provided by DAERA (to J. Dick) showed the importation of Chinese water deer *(Hydropotes inermis*), an invasive deer species, through NI sea ports that were not queried by DAERA, while the regulatory agency for IAS in NI, the NIEA, was entirely unaware of this. The consignment of deer then crossed the border into Ireland and was delivered to an address in Co. Wicklow (J. Dick pers. obs.). In a second example (witnessed by J. Caffrey), a syndicate of Irish Carp anglers placed an order with a dealer in France for a consignment of live Carp, to 14kg in individual weight. The fish were to be delivered to two small lakes in the south of Ireland. No contact was made with the Marine Institute (MI) or Inland Fisheries Ireland (IFI) to seek permission to bring these fish into the country or to make them aware that the fish were being imported. Nor was any effort made to ensure that the Carp were coming from a designated disease-free area in France. The Carp arrived at Rosslare port in a large truck and passed through without any checks. The fish were delivered to the two private fisheries operated by the syndicate and released into the ponds. MI and IFI only became aware of the illegal importation when details were posted by syndicate members on a website.

Further, as part of the recent EPA Research project (Lucy et al. 2021) on IAS, the authors had occasion to engage with the Customs authorities for a number of Irish sea ports to gain permission to erect biosecurity signage, warning travellers from Britain of the dangers relating to IAS. This part of the project was being conducted in collaboration with the GB NNSS, who had already erected similar signs at ports on the other side of the Irish channel. Following countless attempts to engage with the Irish authorities to explain the nature of the campaign, this part of the project was abandoned and transposed to more effective biosecurity communications. Based on this and the above experiences, we fear that ships, shipping routes, ports and harbours are, and will remain for the foreseeable future, likely key pathways for new IAS incursions into the island of Ireland.

Recreational Angling - One significant pathway for aquatic IAS that warrants attention is recreational angling. Angling is a major industry in Ireland and Europe (Hyder *et al.* 2018), and one that is particularly vulnerable to the threats posed by IAS and invasive pathogens. Anglers are very dedicated to their sport and knowledgeable around the subject. However, they are not always as aware as they should be of the threats that IAS and pathogens pose to their sport and, hence, do not place sufficient emphasis on prevention/biosecurity. Anglers in freshwater, and to some extent marine environments, are extremely mobile, regularly moving from one waterway or catchment to another or from one country to another in pursuit of their angling quarry. Angling equipment (e.g. PPE, tackle, boats) is regularly in contact with water and can readily collect and transfer IAS and pathogens. Anglers commonly introduce live bait (fish, invertebrates and plant material; J. Caffrey pers. obs.) into the waters that they fish, much of which is non-native and potentially harmful to the aquatic environment.

Invasive alien plant species (IAPS), often introduced as fragments on PPE, boats or angler's equipment, can readily overgrow water bodies into which they are introduced, resulting in potential flooding issues, significant native biodiversity loss, and economic loss because the waters are no longer available for recreation. Invasive pathogens can result in catastrophic losses of native fishes and invertebrates. Examples of known IAS that impact on recreational anglers, angling or aquatic habitats used by anglers in Ireland include Curly waterweed, Nuttall's waterweed, New Zealand pigmyweed, Zebra mussel, Asian clam, Chub, Crayfish plague, among others (Appendix 1). Examples of IAS that have not yet been recorded in Ireland, or to a very limited extent, but that are likely to be introduced in the near future include Floating pennywort, Signal crayfish, Quagga mussel, Killer shrimp, Chinese mitten crab, Topmouth gudgeon, Salmon fluke, among others (Appendix II).

Ireland has fewer freshwater angling species than England, although large numbers of English anglers, particularly those in pursuit of coarse fish species (e.g. bream, roach, hybrids, tench), annually fish Irish waters for the quality of the fish and habitats available here. However, some of these visiting anglers regularly express displeasure with the perceived paucity of fish species in our watercourses compared to that available in the UK and have threatened to illegally introduce non-native fish species into Irish waters. Numerous reports of non-native fishes in Irish waters have been received over the years by IFI, although few subsequent surveys have recovered live specimens and it is probable that the stocked fish did not survive. However, in the late 1990s or early 2000s, live non-native chub were introduced, probably on multiple occasions, into the River Inny (reputedly by English anglers). These fish survived and grew in the river, but it is unclear if they successfully spawned. A major Chub eradication campaign mounted by IFI in the River Inny successfully eradicated these early introductions to this river system (Caffrey *et al.* 2018). What is worrying from a biosecurity viewpoint is how easily these live fish were brought into the country through our sea ports.

Accidental vectoring of Crayfish plague, probably on anglers' nets, has occurred on multiple occasions in Ireland in recent years, and this poses a serious threat to our protected native crayfish population. Another

pathogen, the Salmon fluke, has been identified by a recent horizon scan exercise (Lucy *et al*. 2020) as a serious and imminent threat to Irish salmon. This parasite could easily be brought into this country on wet nets carried by anglers who regularly fish in waters abroad that are infested with this pathogen. The fact that there is no biosecurity at our ports to intercept these nets and associated angling equipment is leaving the country open to infestation, with the potential to decimate the commercial and recreational salmon sectors across the island, including Brown trout and Sea trout (*Salmo trutta)*. In Iceland and Norway, Customs authorities check anglers entering either country for certificates of disinfection to show that their angling equipment and PPE has been disinfected by a vet within three weeks of travelling.

Another concern relating to visiting anglers to Ireland is the live bait that they carry with them, much of which is non-native. This can include maggots (larvae of a fly or other insect) of several varieties, worms, seeds and, sometimes fish. While we do not know if these live bait organisms are invasive or even potentially invasive, we know that most anglers do not bring unused bait back to their own country, but dump it in the vicinity of their fishing location(s). In order to remove this obvious pathway of introduction of IAS, visiting anglers should not be permitted to bring any live bait through ports onto the island of Ireland, whether animal or plant.

Internet sales – The online buying of materials (e.g. plant seeds) on the internet, with direct delivery into the country, is now commonplace and often without any scrutiny by Custom authorities. This pathway for the introduction of IAS to Ireland is growing (especially through COVID-19 lockdowns), such that increasing numbers of animal and plant species (for example mixed samples of ornamental oxygenating plants for aquaria and ponds) may be coming into Ireland undetected, with the potential for deliberate or accidental release. One recent example is the purchase online and delivery to Queen's University Belfast of Curly waterweed by a student who circumvented the licencing requirement of NIEA for the movement of this species from the wild to the laboratory.

Garden Centres/Pet Shops/Aquarists – Invasive plants and animals are traded openly in such venues and, although EU IAS Regulations have banned much of this trade, there continues to be non-compliance and species "name changing" to avoid the legislation. Thus, for example, Curly waterweed, a listed invasive species in Ireland and a Union list species, has been traded as a generalist "oxygenating pond plant", as have a number of other plant species that serve to oxygenate water (e.g. Parrot's feather, Nuttall's waterweed, Fanwort). It is thought that the Curly waterweed problem in Lough Corrib (Caffrey *et al*. 2008, 2011), which has cost the state in excess of €3 million to date, resulted from a private individual who used this plant to oxygenate her garden pond (in the lower catchment), giving live samples to friends in different areas of the catchment. The initial introduction of the species to Lough Corrib almost certainly came from a pond in the upper catchment (as there is still no Curly waterweed in the lower lake). A number of instances where non-native crayfish, including Signal crayfish and Marbled crayfish, were being sold by aquarists are known in Ireland. In one such instance, Signal crayfish specimens were brought to IFI for identification from a premises in Howth, Co Dublin (J. Caffrey pers. comm.).

Ban on trading and/or holding of particular species – Perversely, the banning of trading and holding of certain species (on national restricted lists or the Union list) may have led to illicit sales of listed IAS (e.g. Muntjac deer – *Muntiacus reevesi*, Slider turtles - *Trachemys scripta,* various Crayfish species, oxygenating plants). Such bans may also lead to their release into the wild by owners to avoid possible prosecution. For example, Slider turtle sightings are increasing in and adjacent to watercourses throughout Ireland (J. Dick pers. obs.), with this author taking 20 turtles into safe keeping from an aquarist whose likely intention was to release them into the wild. Indeed, Slider turtles have recently been reported in several ponds in Ireland and Northern Ireland, and there are unconfirmed reports that these turtles successfully propagated in ponds in the Phoenix Park, Dublin.

Religious releases - Practiced in many regions, such as South East Asia, religious releases of native and non-native species is an increasing concern (Wasserman *et al*. 2018). A release of 200 crabs (likely to be *Cancer magister*) and the Lobster *Homarus americanus* into the sea close to Brighton, southern England, in 2015 highlighted the potential for this vector to result in the introduction of numerous species (Walker 2015). This custom could similarly become established in Ireland, leading to further introductions of aquatic species.

Aquaculture – Importation of organisms into Irish waters for aquaculture (e.g. Pacific oyster spat) has resulted in the introduction of IAS (e.g. the seaweed *Sargassum muticum,* and the Slipper limpet) and associated pathogens and parasites as hitchhikers or contaminants. This includes the Pacific oyster protistan parasite, *Bonamia ostreae*, which can spread to the native oyster, casuing mortality (Lynch *et al.* 2010). The Pacific oyster was considered safe to introduce into Irish waters as the science indicated that it would not be able to successfully reproduce here. Climate change and the associated increasing seawater temperatures, however, likely contributed to the recruitment of the Pacific oyster in natural habitats at a number of northerly locations in the UK and Ireland (Cottier-Cook *et al.* 2017). The introduction of Pacific oyster, for foreshore aquaculture in various Irish coastal locations, has resulted in established wild populations in Loughs Foyle and Swilly, the Shannon Estuary, Galway bay and Tralee Bay (Kochmann *et al.* 2012). In Lough Swilly, a mitigation programme has been undertaken to remove Pacific oyster from certain areas and to relocate native oyster to protected areas in an ongoing Marine Institute project .

1.4 Current IAS governance in Ireland

Table 1 lists the principal agencies and stakeholders that are involved in the management of IAS and provides summary information on their current roles. The Table includes government departments, state agencies, national utilities, including cross border agencies, and a diverse range of stakeholder groups. Northern Ireland departments, the GB Non-native Species Secretariat (GB NNSS) and the British Irish Council (BIC) have also been included because joint governance is necessary for effective management of IAS on the island of Ireland (Lucy *et al.* 2021).

Table 1. Departments, agencies and organisations with roles in IAS management on the island of Ireland.

Depts/Agency/Organisation	Role in IAS management in Ireland
Department of Housing, Local Government and Heritage	Currently the parent department for NPWS, National Biodiversity Data Centre and the Water Forum. Includes a Minister of State with responsibility for Heritage and Electoral Reform.
National Parks and Wildlife Service, NPWS	Manages the Irish State's nature conservation responsibilities under national and European law, and international commitments. Regulatory agency for IAS in Ireland.
National Biodiversity Data Centre NBDC	Repository for IAS data with a dedicated staff member funded to work with NPWS on IAS matters. The NBDC is an Initiative of the Heritage Council. The NBDS is funded by the Department of Culture, Heritage and the Gaeltacht, and the Heritage Council.
An Fóram Uisce	Statutory body that advises the Minister of Housing, Planning and Local Government in respect of water conservation and service issues. It commissioned the current study to produce recommendations for improving governance in relation to aquatic and riparian IAS.
Department of Environment, Climate and Communications	Parent department for the Environmental Protection Agency (EPA) and Inland Fisheries Ireland (IFI).
EPA	Responsible for the Water Framework Directive, which now includes IAS and biosecurity as part of its River Basin Managment Plans. This agency also provides funding streams for research into IAS.
Inland Fisheries Ireland	Provides biosecurity facilities at lake angling competitions, promote biosecurity on their website and in their outreach programmes. This organization manages and partly funds the annual removal programme of the invasive weed, *Lagarasiphon major*, in Lough Corrib.
Local Authorities	Roll-out IAS communication and control programmes throughout the country.
LAWPRO (Local Authority Waters Programme)	Charged with meeting obligations under the WFD and for the development and implementation of River Basin Management Plans in Ireland.
Irish Water	Responsible for the delivery of (clean) water to homes and businesses, and places high emphasis on biosecurity to limit spread of IAS (e.g. crayfish plague). Responsible for treatment of wastewater.
Transport Infrastructure Ireland	Funding a major Japanese Knotweed control programme (€5m) through Local Authorities.
Department of Agriculture, Food and the Marine	Parent department for Marine Institute. Also responsible for transport of pets, an IAS pathway.
Marine Institute	Involved in IAS research including a project lead by Galway Mayo Institute of Technology (GMIT) to develop surveillance methods to facilitate the mapping of IAS distribution in Irish marine habitats.
Waterways Ireland	Cross-border navigational authority responsible for the management, maintenance, development and promotion of over 1000km of inland navigable waterways, principally for recreational purposes.
Loughs Agency	Cross-border conservation, management, promotion and development of the fisheries and marine resources of the Foyle and Carlingford areas. Involved in IAS monitoring.
GB Non-native species secretariat (GBNNS)	Was developed to meet the challenge posed by invasive non-native species in Great Britain. Now provides some support to N. Ireland.
Dept of Agriculture, Environment and Rural Affairs, N.I. (DAERA)	Northern Ireland department, works in co-operation with Ireland on environmental matters.
Northern Ireland Environment Agency (NIEA)	Executive agency within DAERA directly involved with IAS management.
Stakeholder groups (summary list)	Leave No Trace Ireland, Rivers Trusts, Botanical Society of Britain and Ireland, Canoeing Ireland, Triathlon Ireland, Inland Waterways Association of Ireland, angling clubs/federations, marina operators, citizen scientists, hunters clubs/federations, rowing clubs, tackle dealers, bait suppliers, aquarists.

1.5 Legislative and policy gaps regarding IAS in Ireland

Global and European-scale efforts to govern IAS issues revolve around several international conventions (see Table 2). The Convention on the Conservation of European Wildlife and Natural Habitats (Council of Europe, 1979 – the Bern Convention) and the UN Convention on Biological Diversity (CBD), of which Ireland is a signatory, are among the primary international agreements. The principles enshrined in these Conventions are reflected in parallel targets under the EU Biodiversity Strategy. Aichi Target 9 of the CBD Strategic Plan 2011–2020 requires that "by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment" (CBD 2014).

Table 2. Summary list of important international and national legislation governing invasive alien species (IAS) and issues in Ireland and Europe.

Convention on Biological Diversity
Ramsar Convention
Bern Convention
EU Biodiversity Strategy to 2030
EU Water Framework Directive (2000/60/EC)
European Communities (Water Policy) Regulations 2003 (SI 722/2003)
Plant Health Directive (2000/29/EC)
Animal Health Directive (2006/88/EC)
EU (Health of Aquaculture Animals and Products) Regulations 2008
Marine Strategy Framework Directive (2008/56/EC)
Environment Impact Assessment Directive (EIA) 85/337/EEC (as amended)
Wildlife Trade Regulation 388/97/EC
Regulation of the European Parliament and of the Council on the prevention and management of the introduction and spread of invasive alien species (1143/2014)
European Communities (Birds and Natural Habitats) Regulations 2011 (SI 477/2011)
Wildlife Act, 1976 and the Wildlife (Amendment) Act, 2000
Wildlife and Natural Environment Act (Northern Ireland), 2011
National Biodiversity Action Plans – 2nd (2011 to 2016) and 3rd (2017 to 2021)
Invasive Alien Species (Enforcement and Permitting) Order (Northern Ireland) 2019/159

Despite the goals of the CBD, the approach to IAS throughout the Member States (MS) of the EU has been fragmented and inconsistent (Caffrey *et al.* 2014). In addition, as IAS do not respect borders, coordinated action at the European level was deemed more effective than individual actions at the MS level. For this reason, the EU Regulation was introduced in 2015. This legislation establishes a list of IAS of Union concern

(the Union list) and provides for a stringent set of measures to be taken to tackle these listed IAS across the EU. As of February 2021, the list comprises 66 named species (ec.europa.eu). In respect of each of these 66 species, the EU Regulation obliges all MS to prevent and manage the introduction and spread of IAS, as follows: 1) Prevention - prevent the intentional or unintentional introduction of IAS of Union concern into the European Union; 2) Early detection and rapid eradication - put in place surveillance systems to detect the presence of IAS of Union concern as early as possible and take rapid eradication measures; and 3) Management - some IAS of Union concern are already established in certain MS and concerted management action is needed to prevent them from spreading any further.

While the EU Regulation is a ground-breaking attempt to set a common standard for combating IAS across the multinational political jurisdictions of the EU, there are several concerns surrounding the effective implementation of this legislation, particularly for Ireland. Among these is the fact that a number of IAS that are already widespread and highly detrimental on the island of Ireland are not included as species of Union concern, either because their control is considered unfeasible and not cost-effective by some MS (Tollington *et al.* 2015) (e.g. Japanese knotweed), or because they are native to some of the MS (e.g. rhododendron). The lack of a dedicated funding mechanism is another serious cause for concern (Caffrey *et al.* 2014; Beninde *et al.* 2015; Genovesi *et al.* 2015), leaving individual MS to fund all prevention, control and management measures from national resources. The failure of the EU to provide any funding to MS to assist with the implementation and administration of the EU Regulation has already led to problems for its usefulness in Ireland. In one instance, in 2016, a new incursion of Curly waterweed in a lake complex in Co. Kerry was being efficiently managed in accordance with Article 7(2), where MS are required to 'take all necessary steps to prevent the unintentional introduction or spread… of IAS of Union concern' and Article 17 (Rapid eradication at an early stage of invasion) of the EU Regulation, the operation being funded by NPWS. With the operation ≥ 90% completed and the Curly waterweed practically eradicated from the watercourse, national funding ran out. The operation was postponed while additional funding was sought, but no further funding has to-date been secured. In the meantime, the invasive weed has recolonized large areas of the treated lake and spread extensively within the linked necklace of lakes (J. Caffrey pers. obs.). This not only represents a serious waste of money in the previous weed control efforts, but threatens uninfested waters in Co. Kerry and farther afield with the spread of viable propagules from this watercourse *via* anglers, boaters or even birds.

In Ireland, the principal piece of legislation concerning IAS is included in the EC (Birds and Natural Habitats) Regulations 2011 (Statutory Instrument (SI) 477). Regulations 49 and 50 within SI477 deal specifically with IAS, and the Third Schedule lists the priority or high impact IAS (Part 1 – Plants, Part 2 – Animals, Part 3 – Vector material) that are subject to restrictions under these two Regulations. The inclusion of IAS in this Schedule is supported by the Ecoregion 17 Alien Species Sub-group (experts from Ireland and Northern Ireland) and risk assessments conducted as part of the Invasive Species Ireland (ISI) project (see Page 19). Regulation 49 prohibits the introduction and dispersal of such listed species. Under this Regulation it is an offence to plant, disperse, allow or cause to disperse, spread or otherwise cause to grow any plant that is listed in Part I of the

Third Schedule; and it is an offence to breed, reproduce, release or allow or cause to disperse or escape from confinement any animal that is listed in Part 2 of the Third Schedule. Regulation 50 prohibits dealing in and keeping species listed in the Third Schedule, to include having in one's possession for sale, distribution, introduction or release, breeding, reproduction or propagation. Even though the Statutory Instrument that includes these IAS Regulations was commenced in September 2011, Regulation 50 has still not been signed into law because national measures with implications for trade or the internal market require the approval of other Member States and the Commission. This has been a major legislative deficiency that has remained unresolved since September 2011.

In a recent Technical Guidance report from Transport Infrastructure Ireland (TII 2020), the legislation relating to invasive alien plant species (IAPS) in Ireland was referred to as being 'complex, evolving and difficult to interpret' (TII, 2020). This refers not only to the EU Regulation and the EC (Birds and Natural Habitats) Regulations 2011, but also to the range of ancillary legislation relating to these non-native species (e.g. the Wildlife Acts 1976-2018, Planning and Development Acts 2000-2019, use of Plant Protection Products, management of waste).

On a positive front, SI 477 has been rewritten and will implement fully the EU IAS Regulation. It is due to be signed into law in 2021. In this new legislation, provisions for trade restrictions (i.e. Regulation 50 of SI 477) on the list of non-native invasive species in the Third Schedule are now included. It is to be hoped that the complexity and difficulty in interpreting legislation relating to IAPS has been addressed in this new legislative instrument.

Legislation in NI dealing with IAS is included mainly in the Wildlife Order (NI) 1985 and the Wildlife and Natural Environment Act (NI) 2011. As in Ireland, these prohibit the introduction, dispersal, propagation or sale of non-native species listed in Schedule 9. The EU IAS legislation referred to throughout this document has been transposed into UK and NI law post-Brexit as the Invasive Alien Species (Enforcement and Permitting) Order (Northern Ireland) 2019/159. This acts in parallel with the EU Regulation and continues to focus actions on the current list of 66 IAS of EU concern.

Given that the island of Ireland is a single biogeographical entity (Ecoregion 17 within the Water Framework Directive), there is a clear need for greater cross-jurisdictional cooperation in relation to IAS species and management. Fortunately, legislation operating in both territories that governs animal, plant and fish health places a coherent emphasis on the precautionary principle, with robust measures enabling the banning of certain introductions at the point of entry (Turner 2008; Caffrey *et al.* 2014). It is unfortunate that IAS were not included under the umbrella of these strong Directives and Regulations. However, although the agencies responsible for IAS on both sides of the border are in regular contact, there is no overall guiding policy or governance on IAS management between departments and agencies north and south of the border. Contrast this with the GB Non-Native Species Secretariat (GB NNSS), which has responsibility for coordinating the approach to IAS throughout Great Britain. The Secretariat has a small number of full-time staff that are

responsible to a Programme Board that represents the relevant government agencies in England, Scotland, Wales and to a lesser extent NI. The GB NNSS has been very successful in raising awareness regarding IAS issues among a wide audience and in facilitating the development and implementation of appropriate legislation in Great Britain. Further, its participation in the now disbanded Invasive Species Ireland (ISI) project was enormously beneficial to Ireland and Northern Ireland.

While new national IAS legislation is planned for Ireland in 2021, it will be important that the provisions of this legislation are implemented and enforced. There is little point having robust legislation if there is not the will or resources for the regulator to effectively implement and enforce it. It is considered that this may have been the case with the previous legislation, which saw few breaches of the Regulations brought to court. This is reflected in the lack of enforcement of Regulation 49(2) in relation to the illegal movement of Japanese knotweed-contaminated material within the country in recent year. In New Zealand, the sale of a large number of invasive and nuisance plants was legally prohibited to stop their spread in the country. In order to ensure compliance, all commercial nurseries, pet and aquarium shops in that country are regularly inspected. Such an approach is required in Ireland, with punitive penalties for detected breaches.

One of the principal reasons why the NPWS, the regulator for IAS in Ireland, has not been capable of actively pursuing perpetrators in relation to breaches of the Regulations is that the Service is chronically under-resourced (authors, pers. comm.) and is incapable of effectively administering either the national or EU IAS Regulations. It is, therefore, good news that a strategic review of the NPWS is currently being undertaken (commenced in Februarary 2021) and will report to the Minister of Housing, Local Government and Heritage by the end of summer 2021. The aim of the review is to identify any issues, including structure, resourcing, staffing, and governance, that need to be addressed to better equip the NPWS to meet its operational objectives in respect of biodiversity and other responsibilities. The review will inform the future development of the NPWS to enable it to support Ireland's biodiversity objectives in alignment with the UN Decade on Ecosystem Restoration, the EU 2030 Biodiversity Strategy and the forthcoming post-2020 global biodiversity framework. The review will involve extensive stakeholder engagement, an examination of the resources and structures of similar organisations in other jurisdictions, and an overview of the roles and responsibilities of other state bodies and their relationship with NPWS. In March 2021, public consultation opened for this NPWS review and all stakeholders have been given the opportunity to make written submissions; key stakeholders will be invited to participate in online interviews. It is noteworthy that there is specific no mention of invasive species in the terms of reference of the review of the NPWS indicating that IAS management was not identified as strategically urgent in terms of conservation management.

Such a review is also urgently required for the NI governance, implementation, staffing and resourcing of IAS issues, since the statutory body, the NIEA, is even less resourced and effective than NPWS in Ireland. Indeed, the situation is so severe in NI that the only control, eradication and management of IAS is undertaken by academics, students, landowners, National Trust, and other volunteers, with no staffing on the ground by NIEA.

The only known publicised "success" recently recorded by NIEA in its enforcement of the EU IAS Regulation was the euthanisation of a pet raccoon (called Paul) under orders of NIEA, which spurred a public outcry and subsequent investigation. That muntjac deer, Slider turtles, rainbow trout and myriad other invaders are left unmanaged in NI by NIEA is of very serious concern. Clearly, any efforts to manage IAS issues in the Ireland must be matched in NI, or we risk simply exchanging IAS over a border that is invisible to IAS.

There is a need in Ireland for the establishment of a single lead Division that will operate under the aegis of NPWS. This IAS Division must be appropriately resourced, have a clear statutory responsibility for IAS, and be solely dedicated to IAS issues. Such a Division could develop a coherent and coordinated national approach to IAS and lead or facilitate communication and collaboration between government departments, scientific and environmental institutions, NGOs, stakeholders and the public. It could also lead communication and collaboration on IAS issues with the responsible agency in NI. Strong and active collaboration between responsible agencies in Ireland, and between Ireland and Northern Ireland, coordinated through this IAS Division, could drive success in preventing the introduction and spread of IAS on the island of Ireland. This synergy and the establishment of open lines of communication would remove barriers to rapid response or targeted IAS control programmes by ensuring that whatever actions require to be taken could be agreed upon without delay. Currently, there is a disconnect between government departments where each is concerned exclusively with the obligations imposed by Directives or Regulations for which they are specifically responsible. This can impose barriers to urgent and coordinated action, and result in damaging delays when it comes to the potential rapid control or eradication of priority IAS.

There is an urgent and recognised need for an overarching All-Ireland Forum or steering group, which would report to the new IAS Division in Ireland and NIEA/DAERA in Northern Ireland, to coordinate activities relating to IAS on the island of Ireland, similar to Invasive Species Ireland (ISI) that operated two three-year programmes between 2006 and 2013. This now defunct joint north-south steering group was jointly funded by NPWS and NIEA, and effectively brought together scientists, policy makers, practitioners, and stakeholders to advise and steer both jurisdictions regarding IAS matters in Ireland. It had one full-time staff member and up to 25 members from both sides of the border on the steering group. It operated over two three-year terms and very effectively coordinated IAS actions and mitigations between the two jurisdictions. The ISI was dissolved because the small amount of money required for its administration could not be found between the two jurisdictions. Such an All-Ireland Forum would provide a lead in targeting funding for IAS projects, coordinating the efforts of researchers and/or stakeholders to appropriately tackle IAS, prioritising IAS issues and providing both direction and assistance to new IAS Division. The Forum would liaise closely with similar groups in GB and internationally.

While Great Britain and NI (and many other countries) have both prepared comprehensive "Strategies" to tackle IAS in their jurisdictions (Great Britain Invasive Non-native Species Strategy, 2015 and An Invasive Alien Species Strategy for NI, 2013), no national Strategy for IAS has been developed (or is even at the planning

stage) for Ireland. Work towards the development of an IAS Strategy in this country would serve to identify and quantify the nature and extent of the IAS problem in Ireland, while also putting in place measures to mitigate the problems they present.

Coherent national biosecurity guidelines to prevent the introduction and spread of IAS on the island of Ireland are urgently required. Government departments and agencies in Ireland must develop and implement biosecurity protocols for their staff, as stipulated in Target 4.4 of the National Biodiversity Action Plan (2017-2021) and Section 7.5.2 of the River Basin Management Plan for Ireland (2018-2021). In the Interim Review of the implementation of the National Biodiversity Action Plan (February 2020), it was stated that 'little progress on in house/all Ireland plans..' had been made in respect of the development or implementation of biosecurity protocols. Biosecurity Codes of Practice must also be developed for stakeholder groups and members of the public.

Currently, our national Customs service is not resourced or technically equipped to effectively tackle the introduction of IAS through ports and borders into Ireland. Appropriate resources, training and support must be given to the Customs authorities to ensure that they provide an active and competent deterrent to both the illegal or inadvertent introduction of IAS into this country.

Few organisations in Ireland that are charged with the management or maintenance of water or watercourses (e.g. Office of Public Works, Inland Fisheries Ireland, Electricity Supply Board, Environment Protection Agency, Irish Water, Waterways Ireland, Local Authorities) integrate IAS into their day-to-day work programmes. It is important that provisions for IAS surveillance, reporting, control and/or management, for example, are included in all Local Authority County Plans; OPW should target control of Japanese knotweed and other riparian IAS during maintenance or arterial dredging operations on rivers; IFI and EPA staff should record and report all IAS encountered during routine monitoring on watercourses.

Currently, there are no prepared and coordinated Emergency Response protocols or Contingency Plans to deal with new IAS incursions to Ireland (or Northern Ireland). Horizon scanning both within the island of Ireland (Lucy *et al*. 2020) and abroad (Roy *et al*. 2019) has identified a host of terrestrial, freshwater and marine IAS that could likely be introduced to Ireland in the coming years. These plans should clearly identify the communication processes and the lines of responsibility that will operate once a designated IAS has been identified on the island of Ireland. They should also detail the resources (expertise and materials) that are available, provide explicit detail of the practical control methods to be applied and by whom, and clearly indicate the monitoring programmes that will be put in place to ensure that eradication has been achieved. The agency responsible for communication should issue alerts through appropriate channels and provide regular progress reports to responsible authorities, the media and public, as required. Part of the preparation for an Emergency Response should involve: ensuring that personnel in responsible agencies are trained/certificated in targeted control procedures (e.g. herbicide, insecticide or piscicide application, electric fishing, netting, trapping, shooting); ensuring that the required permissions/permits/licences are in place to

allow necessary operations to be conducted, wherever necessary; ensuring that derogations have been provided by responsible agencies (e.g. EPA, NPWS, IFI) to permit the use of prescribed substances or methods, as deemed necessary; and identifying personnel or agencies that will be available to be deployed when targeted species are recorded. These Emergency Response or Contingency Plans need to be developed for use by trained staff in government departments and related agencies, or by other contracted parties. They also need to be shared with or developed in conjunction with NI. The only such response that the authors are aware of is a Contingency Plan to deal with Salmon fluke, prepared jointly by the Marine Institute and Inland Fisheries Ireland, should this notifiable disease be detected in salmon in Ireland (Fish Disease Contingency Plans for Ireland – contingency plan for dealing with outbreaks of *Gyrodactylus salaris* in Ireland, 2014).

While the now disbanded ISI project developed plans for the management of a small number of the IAS, no IAS Management Plans have been developed since that time. It is important that comprehensive Management Plans for listed IAS, and for IAS identified by horizon scan exercises, are drawn up by scientists, policy makers and practitioners. These will detail important information relating to the individual IAS, including who needs to be contacted and what control options are available to tackle identified IAS.

No national IAS education and awareness programmes are currently available in Ireland. Nor are there nationally promoted biosecurity campaigns, such as “Check, Clean, Dry” in the UK. The broad objective of such programmes and campaigns is to ensure that stakeholders and the public are aware of IAS issues and to encourage behavioural change among the population regarding the introduction and spread of IAS, and the implementation of good biosecurity practice. Towards that end, it is urged that the IAS theme should be introduced onto the school curriculum (e.g. Something Fishy, as produced by IFI) and that IAS training provided by experts should be broadly available to stakeholders and public.

Local communities tend not to be directly involved in local or national IAS projects. This is regrettable, as invasive species is a cross-cutting issue that can only benefit from the participation of a wide range of community groups and other stakeholders. The availability of committed, informed and trained community (and stakeholder) groups will provide necessary resources (e.g. citizen science, volunteers, IAS champions) to assist with IAS monitoring, surveillance, early warning, rapid response, control and biosecurity. Community-based groups that are already in place and could be used to collaborate with IAS projects include – Leave No Trace, Clean Coasts, Tidy Towns, Green Campus in schools and colleges, National Spring Clean, River Trusts, local catchment groups, angling cooperatives, local environmental groups/networks, and public participation networks, among others. An excellent example of community involvement in IAS species control and eradication is provided by the IRD Duhallow Life project (2010-2014) where trained local communities and stakeholders successfully eradicated Himalayan balsam from *c*. 30km of channel in the River Allow catchment.

Summary – Legislative and policy gaps for the introduction of IAS into the Republic of Ireland

- A number of IAS that are already widespread and highly detrimental on the island of Ireland (e.g. Japanese knotweed, Rhododendron, Sea squirt) are not included as species of Union concern in the EU Regulation.
- The lack of a dedicated funding mechanism from Europe to assist MS implement and administer the EU Regulation.
- In Ireland, Regulations 49 and 50 of EC (Birds and Natural Habitats) Regulations 2011 (Statutory Instrument 477) deal specifically with IAS. While these Regulations were signed into law in September 2011, Regulation 50 has still not been commenced by the Minister as it is deemed to be not compatible with aspects of EU trade regulations.
- Given that the island of Ireland is a single biogeographical entity (Ecoregion 17 within the Water Framework Directive), there is a clear need for greater cross-jurisdictional cooperation in relation to IAS species and management. However, there is no formal cooperative mechanism for joined-up working across government departments and agencies north and south of the border.
- It is considered that there has been a lack of enforcement of existing IAS legislation on behalf of the regulatory agency (NPWS). It is clear that NPWS has neither the staff nor resources to effectively implement, administer or enforce the national or European IAS legislation.
- Currently, there is no single lead agency or authority in Ireland that is appropriately resourced, has a clear statutory responsibility for IAS, and is solely dedicated to IAS issues. It is a matter of urgency that an IAS Division, working under the aegis of NPWS, is established and given the level of funding that it requires to successfully discharge of its responsibilities.
- There is a disconnect in Ireland between government departments in Ireland where individual departments are concerned exclusively with the obligations imposed by Directives or Regulations for which they are responsible.
- There is an urgent and recognised need for an overarching All-Ireland Forum or steering group, reporting to the new IAS Division, to coordinate activities relating to IAS on the island of Ireland, similar to Invasive Species Ireland (ISI) that operated between 2006 and 2013.
- Unlike Northern Ireland, UK and many other countries, Ireland has not developed a National Strategy for IAS, nor is one being planned for the near future. Nor do government departments and agencies in this country have agreed national biosecurity guidelines for staff and stakeholders to prevent the introduction and spread of IAS in Ireland.
- Our national Customs service is not resourced or technically equipped to effectively tackle the introduction of IAS through ports and borders into Ireland.
- Few organisations that are charged with the management or maintenance of water or watercourses in Ireland integrate IAS into their routine and ongoing work programmes.

- Currently, there is a paucity of prepared and coordinated Emergency Response protocols or Contingency Plans to deal with new IAS incursions to Ireland. A list of IAS deserving of urgent attention is available in recent horizon scan exercises conducted in Ireland and the UK.
- No detailed Management Plans for IAS that are present in Ireland have been prepared since the ISI project was abandonded in 2013.
- No nationally sponsored or promoted IAS education and awareness programmes or biosecurity campaigns are currently available in Ireland.
- Local community involvement in local or national IAS projects is minimal and should be resourced with training and other supports.

1.6 Current barriers to managing the introduction and spread of IAS in Ireland

The barriers to both restricting introductions of new IAS and managing established IAS in Ireland are summarised together in this Section.

There is no national strategy to monitor for aquatic IAS, despite the fact that we now have expert information on the species most likely to arrive in the next few years and can target these door-knockers (Lucy *et al.* 2020). Lack of effective bespoke monitoring programmes for IAS is a major barrier in terms of introduction and management of aquatic IAS. Water Framework Directive (WFD) monitoring carried out by different organisations (e.g. EPA, IFI, MI) will take note and report any IAS recorded, but this is based on surveying of specific waters, with ecological monitoring undertaken in three year cycles. Within three years an IAS can establish and create major ecological impacts (Lucy *et al*. 2014). If early detection does not take place, any opportunity for successful eradication is lost and management becomes more unyieldy and costly. Apart from WFD monitoring programmes, detection is largely reliant on independent ecological consultants, naturalists and citizen scientist that record IAS in an *ad hoc* serendipitous manner when carrying out surveys of their own, then relaying the information, in their own time, to independent experts, competent agencies or the NBDC.

While legislation both domestically and at the European level is extensive, its implementation and enforcement is seriously underwhelming. This is primarily due to lack of resources – the EU IAS legislation comes with no dedicated funding and domestic funding is often fragmented, piecemeal and not fit for purpose. For example, short-term programmes of eradication/control work that then cease simply allows IAS problems to re-emerge and even worsen. In terms of introductions, there has been no implementation of IAS species biosecurity measures, personnel and training at customs and ports to prevent introductions of fish, invertebrates (*via* live bait) or aquaic plants. This is likely due to the common disconnect between government departments involved in trade and transport and those involved in environment or marine, which will not

improve until there is the genesis of an overarching national priority with robust governmemt policy to prevent and manage invasive species in Ireland.

While many organisations (see Table 1) have made concerted efforts to manage aquatic invasive species, there is a critical underfund that either prevents or reduces the adequate effort required for the sustained management required.

Another contributor to the barriers is the lack of legal enforcement and implementation of prosecutions and fines, with perceptions needing to change such that "polluters will pay". There is also a serious lack of accessible information with regards to IAS and biosecurity available to travellers, in terms of communications and awareness-raising, which falls under the enhanced biosecurity measures discussed above and below. As an illustration of the urgency of removing these barriers, the range of pathways for the 40 horizon scan IAS across freshwater, marine and terrestrial environments (Lucy *et al.* 2020) necessitate a diversity of prevention and management measures. These include effective risk assessment, improved detection, recording and inspection at ports and airports, full implementation of the Habitats Regulation in Ireland (EC 2011) and the Wildlife and Natural Environment Act (Northern Ireland) (NI 2011, 2019), plus the EU Regulation, to include management of trade, including internet trade (see Section 1.2).

Moreover, we have identified particular groups, such as anglers, that pose great risks of bringing in and spreading IAS, both intentionally and inadvertently. While biosecurity devices (e.g. washing and disinfection facilities) can be cheap and effective, they are simply not being adopted by the responsible bodies or by water users. Indeed, we can show examples of disinfection equipment in place on prime angling lakes that are now being used for dumping litter! The internet trade also permits the introduction of marine and freshwater IAS. With the fast courier services available and the lack of adequate customs checks, there is no effective barrier to prevent this pathway of IAS introduction.

2. Mechanisms for restricting IAS introduction and spread in Ireland

There is an identified requirement for increased awareness of IAS amongst both the public and the legislature. Outreach programmes for the public are needed to minimise accidental introductions of IAS. Knowledge exchange between scientists, practitioners and policy makers must be encouraged to improve channels of communication to improve understanding of individual roles and develop a co-ordinated approach to IAS management. Knowledge transfer between those engaged in research, policy and management is of the utmost importance if successful IAS management initiatives are to be implemented. These initiatives must inform society's perception of IAS and take into account the demands of stakeholders from all sectors (Caffrey *et al*. 2014).

Measuring the success of biosecurity measures to prevent incursions of IAS is very difficult, as the absence of IAS from new locations could be down to many variables, not least chance. There is more evidence available for disease prevention through biosecurity, such as the stringent customs measures put in place to prevent the spread of foot and mouth disease. The New Zealand Biosecurity Act, published in 1993, is world leading in timing and implementation, and has seen demonstrable outcomes in reducing organism incursions into that country (Hulme 2020). However, even although proving the effectiveness of biosecurity is difficult, there are good economic, social, ecological and other arguments to spend on and plan biosecurity measures for IAS to save on what could be catastrophic costs, especially if biosecurity encompasses animals, plants and pathogens holistically (Hulme *et al.* 2020). Moreover, there are some notable international IAS biosecurity success stories, and failures, examples of which are presented below.

2.1 Emergency response procedures for new IAS incursions

Few if any emergency response (ER) procedures are in place in Ireland and most responses are, at best, reactive (and only if money, resources and appropriately trained personnel are to hand). In the past, IFI had a dedicated team of research staff available who, together with regionally based fishery staff, were on-hand to react swiftly and under scientific guidance to newly discovered incursions nationally (e.g. Curly waterweed in Lough Corrib, Asian clam and Dace in the River Barrow navigation, Bloody red shrimp in Lough Ree (with QUB), Chub in the River Inny, Chinese mitten crab in Co. Waterford). This rapid response capacity reduced the potential impacts of IAS incursions, even if it was not possible to eradicate the targeted species. Currently, some private contractors are trained and available to deal with certain IAS incursions (e.g. Japanese knotweed) but only where specific funding is available.

While there are some IAS 'alert' mechanisms in place in Ireland, such as online reporting of IAS sightings to NBDC, the IFI hotline or via NIEA in NI through maintenance of the ISI website, there are few, if any, national or local practical emergency response procedures for new IAS incursions (with a few notable exceptions; eg

salmon fluke). The only Contingency Plan that we are aware of that is in place and ready for operation is that for the Salmon fluke (Operations Manual for Containing and Eradicating *Gyrodactylus salaris* in Ireland, Marine Institute and IFI 2014). While a number of Contingency Plans for IAS, such as Muntjac deer, Wild boar, Chinese water deer were considered by the ISI project, these were never finally agreed and have never moved beyond paper exercises.

Certainly, individuals such as the current authors are sometimes called upon when IAS are detected, but this is *ad hoc* and rarely of practical use other than for research. For example, J. Caffrey is alerted to new Curly waterweed and Asian clam outbreaks, F. Lucy when Zebra mussels are detected, and J. Dick when various species, such as Muntjac deer and Slider turtles are discovered. However, these individuals are not in the position (usually) to act decisively on such IAS outbreaks. The staffing issues raised above are very relevant here, as there are simply not sufficient (or any) trained staff and resources to put in place and deliver IAS emergency procedures. As an example, Slider turtles are well known in several river, lake and pond locations in Ireland/Northern Ireland, yet apart from efforts by J. Dick and students, no effective actions to remove them from the wild have been implemented. The value of Invasive Species Ireland, as detailed above, did in some cases ensure some emergency responses by the current authors and their associates. This reliance on a few individuals, outside of statutory bodies, is clearly welcome but entirely unsustainable and cannot be sufficiently effective.

On a positive note, the recently completed EPA project on the 'Prevention, Eradication and Management of Invasive Alien Species' led by the current authors (Lucy *et al.* 2021) has developed tool boxes for the eradication, control and management of two high profile IAS - the terrestrial plant Winter heliotrope (*Petasites pyrenaicus*) and Asian clam. Several other IAS could be tackled using these novel control methods, to include Killer shrimp and a number of invasive macrophytes. We propose that these and other emergency response tool boxes receive more research and development resourcing, as their field deployment could curb the major impacts and costs of these and other IAS. In Appendix III, we present a summary of actual and potential biosecurity, eradication, control and management measures that could be deployed to tackle IAS in Ireland.

Close cooperation should be encouraged between the wildlife-focussed agencies (e.g. NPWS/NIEA) and the more agricultural-focussed agencies (eg DAFM/DAERA), as the latter have well resourced emergency response procedures to react in a timely and efficient manner to problem species. For example, J. Dick is a member of the DAERA Humane Slaughter Team, which has collaborations with Ireland, and which is resourced and trained to deal with agricultural, domestic and wildlife carriers of notifiable diseases, such as rabies and foot and mouth. With a little more cooperation, such initiatives could broaden their remit to include IAS emergency response, mirroring the very effective inter-agency cooperation found in the New Zealand approach to managing IAS, which have moved from just legislation to actual coordinated early detection and rapid reaction to IAS (Brenton-Rule *et al.* 2016).

Two of the relatively few case studies for early response to new IAS incursions are presented below.

Case Study 1: Early detection and rapid response to control a new incursion of Curly waterweed (*Lagarosiphon major*) Curly waterweed is a highly invasive submerged plant that, until 2016, was recorded growing wild in only one natural watercourse in Ireland - Lough Corrib. Curly waterweed is an IAS of Union concern i.e. a species that require action across all Member States in the EU. Curly waterweed is a submerged macrophyte native to southern Africa. In suitable lake habitats it grows vigorously and rapidly forms extensive monocultures. As only female plants are present in Ireland, fragmentation is the main method of spread. It was first recorded in Lough Inchiquin, Co. Kerry in 2016 and according to Article 13 of the EU Regulation, required rapid eradication. As this lake is an active Brown trout fishery, it is probable that viable stem fragments of the plant were brought to the lake attached to boat trailers or boats. It is known that stem fragments can remain viable out of water, in damp conditions, for at least one day.

Dense infestations of Curly waterweed outcompete native macrophytes for space and through the shading effect under dense surface canopies. The proliferation of vegetation in the water body can also alter the physico-chemical characteristics of the water, in addition to significantly altering water movement patterns. The latter has the potential to cause serious flooding as the progress of water through the lake is slowed.

Dense stands of Curly waterweed reaching the surface in Lough Inchiquin (left) and jute matting being laid over Curly waterweed in the lake (right) in 2016.

Within weeks of the Curly waterweed being recorded in Lough Inchiquin, the extent of the infestation was mapped, and a control/eradication plan was put in place. This involved the use of scuba divers to hand-pull the weed in shallow water and to cover larger weed beds with light-blocking jute matting in deeper water. These methods have proved to be very effective in controlling Curly waterweed in Lough Corrib (Caffrey *et al.* 2011). Weed control operations commenced in 2016 and continued in 2017, reducing the extent of the weed originally present by up to 90%. Because of funding difficulties, however, weed control plans for 2018 were postponed. As a direct consequence, the Curly waterweed has regrown and continued to spread not only in Lough Inchiquin and through the necklace of lakes downstream of it.

Case Study 2: Early detection and rapid response achieved eradication of Water-primrose (*Ludwigia grandiflora*);
Water-primrose is considered native to South, Central and the south-east of North America. It is listed as an invasive plant in the Third Schedule (Part 1) in the EC (Birds and Natural Habitats) Regulations 2011 and a species of Union concern in Europe in the EU Regulation on IAS (1143/2014). It is an aquatic and marginal herbaceous perennial plant that can form extensive floating mats on the water surface but can also establish large emergent stands to 1 metre tall along the edges of shallow lakes, ponds or wet meadows. The leaves are dark green with a distinct midrib and prominent branched veins, borne on short stalks. The stems are reddish, fleshy and can be floating or emergent. The flowers are up to 30mm in diameter, bright yellow and very conspicuous.

Stand of emergent Water-primrose at the edge of an artificial pond in Sneem, Co Kerry in 2009.

Water-primrose plants have been recorded from artificial ponds in two locations in Ireland – in Clarecastle, Co. Clare (since filled in) and Sneem, Co. Kerry. Confirmation of the presence of this invasive species at both locations was recorded in 2009. Water-primrose may have been imported into Ireland via the horticulture and aquarium sector for sale to the public, although no details of any sales within the country have been uncovered. It could also have been inadvertently introduced as a hitchhiker in consignments of imported species.

Water-primrose can form very dense and often impenetrable surface mats of vegetation in small watercourses. Such large stands can lead to a depletion in oxygen levels in the water while also blocking incident light from native macrophytes. Its aggressive growth in suitable habitats can also out-compete native plants in and at the margins of small lakes and ponds.

In Clarecastle, Co. Clare the pond was serving no purpose, so it was drained and filled in. The Water-primrose was buried beneath approximately two metres of soil. Subsequent monitoring of the site recorded no Water-primrose plants.

Permission from the landowner in Sneem, Co. Kerry was granted to eradicate the small number of Water-primrose stands that were present in the two artificial ponds. The aerial leaves and stems of the plants were sprayed with glyphosate (in a formulation that was cleared for use in or near watercourses) in summer 2009. The site was revisited in autumn 2009 and any remaining green tissue was again sprayed with glyphosate. Subsequent site visits in 2010 and 2011 recorded no Water-primrose in these ponds.

2.2 Biosecurity actions for established invasive alien species

Below, a number of national and international case studies of biosecurity actions targeted against established IAS are presented. It is difficult to label these as having successful or unsuccessful outcomes as it is difficult to measure the success or otherwise of biosecurity actions at one moment in time. Once measures are put in place, from then onwards, we can only attempt to measure their success using the knowledge available at that time. It is always possible that the *status quo* may change (from successful to unsuccessful), due to either accidental or deliberate introductions or reintroductions, and that this may take some time to measure due to constraints in early detection of a new IAS incursion.

Case Study 1: Great Lakes, North America The Great Lakes of North America have been heavily invaded (e.g. Zebra mussels and Spiny-water fleas) primarily through transport of IAS in transoceanic ballast water, causing massive ecological and economic damage (Rothlisberger *et al.* 2012). Canada and the US thus developed new and stringent biosecurity regulations on ballast water, primarily its exchange at sea to kill any freshwater/brackish IAS present in ballast tanks (Government of Canada 2006; Saint Lawrence Seaway Development Corporation 2008). Prior to 2006, there was, on average, a new Great Lakes invasion every 28 weeks (Ricciardi 2006), the highest invasion rate globally at the time. But since 2008, there have been no or very few new invasions, with invasion rate now down at least 80% (Ricciardi & MacIsaac in prep.). This invasion reduction is attributed to strict inspection and enforcement (Ricciardi & MacIssac in prep.) and is a lesson that could be learnt for Ireland, which has received many aquatic IAS *via* shipping and is predicted to receive many more (Lucy *et al.* 2020).

Case Study 2: Chub (*Squalius cephalus*) in Ireland Chub is indigenous to many parts of Europe, including England, but is non-native and potentially invasive in Ireland. In late 2005, three live Chub were caught in Ireland and it has never been established if they arrived *via* a single or multiple introductions. While no prepared emergency response procedure to remove potentially invasive fish species in Ireland was in place, CFB embarked on a programme of measures to control and possibly eradicate Chub from the River Inny. In 2006, a major electric fishing operation involving 15 staff members in five boats electric fishing *c*. 40km of the River Inny. During this operation, some 17 Chub were captured and euthanised. The river was electric fished annually between 2007 to 2013, with no further Chub being captured after 2010. The fact that a single Chub was caught on rod and line in the river in 2020, in a section that was extensively electric fished in the past and closely monitored up to 2020, suggests that this fish may have resulted from an illegal reintroduction event, probably in recent years. The fact that it would be simple for live Chub to be illegally brought into the country and introduced to rivers in Ireland represents a serious failure on behalf of the Customs authority and further points to the distinct lack of biosecurity at our ports.

Case Study 3: Wakame (*Undularia pinnatifida)* in the Chatham Islands When the marine alga *Undularia pinnatifida* was recorded on the hull of a recently sunk fishing trawler in coastal waters off the Chatham Islands, New Zealand in 2000, immediate action was taken to eradicate this invasive species of the kelp family. No records of this species had been recorded from these islands previously and eradication was achieved by a combination of heat treating the entire hull using water heated to 70^{o}C and using an underwater flame torch (Wotton *et al*. 2004).

Case Study 4: Crayfish plague (*Aphanomyces astaci*) in Ireland *Aphanomyces astaci* is a fungus-like organism that causes the lethal Crayfish plague in freshwater crayfish. Crayfish plague was first recorded in Ireland in 1987, resulting in the decimation of protected White-clawed crayfish (*Austropotamobius pallipes*) populations in several midland lakes. In 2015, however, a confirmed outbreak of plague was recorded in the Bruskey River, a tributary of the River Erne, where thousands of the native White-clawed crayfish were killed. It is suspected that the infestation was introduced to Ireland in 2015 by anglers who had fished in infested English waters and brought live spores back on their damp nets. In order to stop any further introductions of the plague into Ireland and to limit the spread of the disease, NPWS and NBDC issued species alerts to warn anglers, boaters and water users generally of the presence of the plague, its impacts on biodiversity, and to advise them to take precautions not to inadvertently introduce it to the country or spread it from one watercourse to another. Staff within organisations that had dealings with water, such as IFI, WI, EPA, ESB, were advised to be on the lookout for signs of the plague (dead White-clawed crayfish on the river or lake bed) and to report any such instances immediately to NPWS. The biosecurity actions taken appeared to have worked as no further reports of plague were reported in 2015 or 2016. However, in 2017 further infestations were recorded in rivers in counties Tipperary, Waterford and Carlow. In 2019, in response to the increased number of catchments affected by plague, NPWS recommended the implementation of Emergency Containment Measures to stop the spread of the disease. As such, all water users were requested to operate a temporary ban on moving water sports and angling equipment on or out of infested rivers. No further outbreaks were reported for 2020 or thus far in 2021, probably reflecting the lack of movement or recreation on watercourses because of COVID-19. However, Crayfish plague is currently regarded as an established invasive species in Ireland that is spreading.

Case Study 5: Rainbow trout (*Onchorhyncus mykiss)* in Northern Ireland Aquaculture and fish farming have contributed many IAS across the world, such as Pacific oysters and Brown trout (*Salmo trutta*). Many of these have been deliberate releases, but in some cases resulted from accidents involving supposedly biosecure facilities. One recent and instructive case happened in NI in 2017 (and potentially affects Ireland), where 380, 000 Rainbow trout escaped when flooding breached their containment facilities at Rock's Lodge, River Strule, Co. Tyrone (Whelan 2017). The facility was ostensibly secure against extreme flooding events with 1 in 50 year frequencies, but was breached in August 2017. This caused considerable damage to local fisheries in the short-term, with unknown long-term damage (e.g. these fish breeding and returning as Steel-head trout). The response from Loughs Agency and DAERA involved considerable cost and effort, such as disposing of thousands of dead and caught fish, and research is ongoing as to impacts (Loughs Agency 2018). This highlights that there can be no guarantees that non-native species held in facilities in Ireland/Northern Ireland will be secure from escapes, particularly with climate change forecasts of increased flood events, and potential establishment and impact.

Case Study 6: Salmon fluke (*Gyrodactylus salaris*) in Ireland and UK Salmon fluke poses immense threats to salmon fisheries throughout Europe, with Norway experiencing total depletion of juvenile salmon in infested regions (Denholm *et al.* 2016). Control measures, using rotenone (poison) have, however, been successful and there are provisions to ban the import of live salmonids into the UK and Ireland unless from areas free of Salmon fluke (EU decision 96/490/EC). Diagnostic techniques have also been developed based on DNA probes to discriminate between species of *Gyrodactylus* that may aid in detection of pathogenic species and strains (Cunningham *et al.* 1995).

3. Management of IAS already established in Ireland

Management actions on specific aquatic IAS began only in the 1990s and have to-date been delivered on a 'once-off' or on a 'year-to-year' basis using existing human and financial resources of the agencies who have championed and actioned specific control measures. Section 1.4 outlines the current national IAS governance in Ireland and the challenges that exist in terms of sustained resourcing and making co-ordinated plans to manage the introduction, spread and control of aquatic IAS on this island. Pathways of introduction and spread within Ireland need to be addressed *via* pathway action plans, clear lines of governance between and among competent authorities need to be established in a sustainable manner, legislation needs to address early eradication of high impact invaders, and communication and awareness programmes need to be delivered to a range of target audiences (Caffrey *et al.* 2014). We present a number of case studies below.

Case Study 1: Ongoing management to control established invader Curly waterweed (*Lagarosiphon major*) in Lough Corrib Curly waterweed is a submerged perennial macrophyte that grows vigorously in suitable lake habitats. As only female plants are present in Ireland, it spreads within and between watercourses via fragmentation (viable plant fragments). In littoral habitats to 5m deep, the plant can form extremely dense surface vegetation canopies at the water surface. These impede navigation, angling and water movement, as well as blocking light from penetrating the water column to enable photosynthesis among submerged native plants. The invasive plant arrived in Ireland through the aquarium trade as an oxygenating plant for use in artificial watercourses and is relatively widespread in such artificial ponds throughout Ireland.

Curly waterweed at Rinaroon Bay, Lough Corrib before management and during weed cutting.

Curly waterweed was first confirmed in a natural watercourse in Ireland (Lough Corrib) in 2005. It spread rapidly and widely in this large lake in subsequent years, primarily as a consequence of boating and angling activities. Research conducted by IFI developed a suite of control procedures that included hand pulling in shallow water, mechanical cutting using V-blades and harvesting, and covering the weed with light-occluding jute matting. These methods have been employed by a dedicated weed control team working on Lough Corrib under IFI direction from 2013 to date. Weed management operations to date have achieved significant control of this invasive weed as few surface vegetation canopies are currently evident on the lake and water-based activities can continue, unobstructed by the weed. In addition, the risks posed for native macrophytes, macroinvertebrates and salmonid fishes are minimised. This

management programme in Lough Corrib has cost in the region of €4 million and the annual cost of managing the weed in the lake is in excess of €300,000. In the absence of this control, Lough Corrib would also have been lost as a world class, wild salmonid fishery and many of the protected species and habitat for which the lake in renowned would have been compromised. The net loss to the environment, and to the local and Irish economy, would have been appreciable.

Case Study 2: Management efforts to control Asian clam (*Corbicula fluminea*) in Ireland The Asian clam is a freshwater bivalve native to Southeast Asia, Australia and Africa. It is yellow-brown or black and the shells are light purple on the inside. The clam has concentric, evenly spaced, thick ridges or rings and a prominent external ligament. Mature clams are usually < 25mm but can grow to 50mm. The Asian clam inhabits lakes, canals, rivers and streams and is capable of burrowing in soft sediment to a depth of c. 20cm. It is a filter feeder but is also capable of collecting food from the sediment using its extendable foot. It is a hermaphroditic species, with an average annual fecundity of > 68,000 (Williams and McMahon 1989). Typically, this species reproduces twice a year, initially from spring to summer and again in late summer to autumn. Released juveniles anchor to sediments, vegetation or hard surfaces by means of a single mucilaginous byssal thread. The life span of Asian clams is variable but, on average, ranges from 1 to 5 years.

The Asian clam was first reported in Ireland in 2010 in the freshwater tidal sections of the Rivers Barrow and Nore. Populations have subsequently been reported at various locations in the River Shannon, the River Erne and more recently in the River Foyle. It is thought that initial introduction to Ireland was intentional – as a food item. The subsequent spread of this highly invasive species within the country has likely been facilitated by the transportation of juveniles attached to anglers keep nets and to the hulls of boats *via* their sticky byssal threads.

Specimens of Asian clam (Corbicula fluminea) from the River Barrow (left and middle) and a dense layer of live clams on the bed of the River Barrow at Poulmonty in 2015 (right).

The Asian competitively impacts on native macroinvertebrate communities, significantly reduces phytoplankton biomass, alters benthic habitats and substrates, and adds biologically available nitrogen and phosphorus to aquatic ecosystems.

Good biosecurity practice represents the best method to limit the further spread of the Asian clam in Ireland. Cleaning and disinfection of all PPE and equipment that comes into contact with water will significantly reduce the risk of spread (Barbour *et al.* 2013). It is particularly important that anglers disinfect their landing and keep nets after each fishing trip and particularly before entering a new watercourse or catchment.

While considerable efforts were made to control the populations of Asian clam in the River Barrow (*via* dredging, benthic barriers, salt), these met with little success. Recent studies conducted as part of an EPA Research project (Lucy et al 2020) have developed novel control methods (thermal shock using steam, open-flame, pelleted dry ice) that could potentially achieve a high level of control of this pernicious invasive species. It will be important to conduct field trials using these

novel Asian clam control methods, singly and/or in combination, in order to establish their value as tools for reducing or even eradicating populations of this invasive species in Ireland.

Case Study 3: Biosecurity to stop the spread of Crayfish plague (*Aphanomyces astaci*) *Aphanomyces astaci* is a fungus-like organism that causes the lethal Crayfish plague in freshwater crayfish. Its natural range is in North America. It is a highly infectious disease and is listed as among the 100 worst invasive species in Europe by DAISIE. Infection of crayfish with Crayfish plague is accompanied by few obvious signs and the first indication that the watercourse is infected is dead crayfish bodies on the river or lake bed. The infectious free-swimming zoospores are capable of surviving outside the host and out of water, in damp conditions, for several days. Thus, the organism can be inadvertently spread on damp fishing equipment, boats or any equipment used in infested waters.

Dead crayfish at a river's edge having been killed by Crayfish plague. (source – European-crayfish.org)

Crayfish plague was first recorded in Ireland in 1987, but not again until 2015 when the plague killed thousands of native crayfish in the River Erne catchment. Further infestations were recorded between 2016 and 2019 in several river catchments. It is currently regarded as an established invasive species that is spreading. It is probable that infectious zoospores or cysts were introduced from the UK or Europe on damp fishing nets used by anglers or in the wet wells of kayaks or boats brought here from infected waters abroad. Spread within the country has probably been mediated by the movement of anglers, boats and machinery from infested to non-infested waters.

Establishment of the Crayfish plague in Ireland could result in 100% mortality among the protected White-clawed crayfish (*Austropotamobius pallipes*). Throughout Europe, the White-clawed crayfish has been decimated by the plague. The elimination of this species from Ireland could facilitate the establishment of non-native crayfish species from the UK or Europe. Experience here has shown that these species can have a severe impact on native habitats and species (e.g. macrophytes, macroinvertebrates and fishes).

As it is impossible to kill the infective propagules in affected watercourses, reaction has focused on preventing further entry of the organism into the country and preventing further spread within the country by adopting rigorous biosecurity protocols. From the earliest reports of the plague in the country in 2015, Government departments, the NPWS, the NBDC and other agencies embarked on a programme of awareness-raising among stakeholders and the public. Crayfish plague Alerts were issued by NBDC and the Marine Institute. Anybody who had reason to come into contact with water was urged to observe the 'Check, Clean, Dry' protocol once they leave the water. Where it was not possible to dry gear or equipment sufficiently, the protocol required it to be disinfected or steam cleaned with hot water. Further, Irish Water commissioned a targeted biosecurity protocol for their staff and consultants in order to ensure that the disease was not spread by them from infected to non-infected watercourses. Infected rivers were closed to all amenity and recreational pursuits, and even non-essential maintenance work on these waters was postponed.

4. Education and awareness

4.1 Importance of education, awareness and communication

There is an identified requirement for increased awareness of IAS amongst both the public and the legislature. Outreach programmes for the public are needed to minimise accidental introductions of IAS. Knowledge exchange between scientists, practitioners and policy makers must be encouraged to improve channels of communication, to improve understanding of individual roles, and to develop a co-ordinated approach to IAS management. Provision of financial costs by the water industry and other impacted stakeholders can better inform economic models and subsequent policy, which in turn may benefit the stakeholders in the longterm. There is also a need to disseminate the advantages of new technologies. Policy makers also require education on the existence of non-market costs and, in order to evaluate these costs, biologists need to effectively network with socio-economists to develop combined analyses. If we are to develop coordinated international best practice for biosecurity and risk assessment, there must be a consistent and informed approach. This requires knowledge-sharing and networking among the Irish and with international experts (Caffrey *et al.* 2014).

Currently, there are no national IAS education and awareness programmes in Ireland, meaning that stakeholders and members of the public that are interested in learning about IAS or biosecurity have no structured guidance. Environmental issues and their mitigation clearly benefit from educational exposure and awareness campaigns, alongside citizen science (e.g. climate change, plastic pollution, 'leave no trace'). The availability of informed IAS education and awareness programmes builds capacity and skills among participant groups, to the ultimate gain of ongoing or proposed IAS projects. Community involvement in national or local IAS awareness and management programmes not only ensures ongoing support in terms of local manpower and resources, but also ensures the long-term sustainability of these projects. To not actively engage with communities and stakeholders (e.g. in schools, clubs, environmental groups) in respect of IAS issues is to miss out on a continued source of support and assistance. This is a bottom-up, grassroots strategy that has a shared vision and a sense of collective ownership.

Davis *et al*. (2020) showed that outreach is an important element of scientific communication and a prescribed element of many projects, but few scientists have training in communications. This Broadcast media and social media have the capacity to reach a wide audience, but have a low percentage of interaction. Workshops and citizen science events tend to reach a much smaller audience, but generate greater levels of engagement. Understanding these dynamics is important in designing an effective communications plan, which uses the minimum number of resources to generate maximum impact.

Davis et al. (2018) showed that, by devoting human resources to outreach and structuring efforts around a robust communications plan on a specific invasive species (winter heliotrope), it is possible to establish a large audience and become a trusted resource for specific information. When the broad reach of broadcast media and social media is cleverly used to support more focussed outreach events such as citizen science, public events and workshops, a momentum can be generated around topics such as IAS, which can be sustained.

The EU project 'Communication and Understanding of Invasive Alien Species' (2020-2023), co-led by IT Sligo (FL) and UK-Centre for Ecology and Hydrology is carrying out a series of four workshops, beginning in March 2021, with five diverse clusters comprised of individuals from competent agencies, NGOs and industry stakeholders in freshwater angling, soil, aquatic ornamentals, the pet trade and forestry throughout the EU. This project aims to improve management of IAS by increasing the awareness of pathways in each of these clusters to reduce incidence of introduction and spread. The deliverables at the end of the project will be materials for IAS prevention campaigns – these will be delivered in a co-creative process across each stakeholder group. Thus far, the first workshops, for each of the five clusters, have been very effective in terms of engagement, improved communication and in developing pathway networks, and this process could be easily carried out at a national level if resourcing was made available.

4.2 Recommendations for improving communication of IAS issues

In the broader community, outreach needs to be carried out at all levels of engagement from primary schools to elder citizens. There is a real opportunity to do this through existing community groups, *via* LAWPRO, Rivers Trusts, local Environmental Networks, among others. This is already happening but it needs more co-ordination and greater and sustained resourcing. Existing projects (e.g the CANN Interreg project, (https://thecannproject.org/) are engaged in biosecurity actions *via* community workshops and social media but once the projects end, the local social links networked with related IAS actions lessen and often dwindle away. We need to develop a national communication schedule that is managed by a single agency that communicates with project leads, agencies and NGOs to capture the different communications annually on aquatic IAS, make suggestions to the parties involved and push out the communications *via* social and traditional media. Industries and other stakeholders directly impacted by IAS, will be encouraged to share economic data, to inform IAS costing models and subsequent policy. In this manner, there will be a co-ordinated effort to improve communication of IAS issues and awareness raising among stakeholders and the general public in Ireland.

4.3 Examination of international case studies of IAS education and outreach programmes

Successful case study 1: Preventing the introduction of Northern Snakehead fish (*Channa argus)* to Canada The Canadian federal government conducted a biological risk assessment to determine the risk of Northern snakehead in Canada. This assessment included evaluating the risk of survival, reproduction and spread of this species, as well as its pathogens, parasites or hitchhikers (e.g. other invasive species) should Northern snakehead be introduced into Canada. These components were assessed using the best available information on its biology, potential vectors of introduction, and impacts in both native and introduced ranges. Since then a number of agencies have implemented sustained efforts to provide education and outreach, including the Invasive Species Centre (https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/fish-and-invertebrates/northern-snakehead/) and Fisheries and Oceans Canada (https://www.dfo-mpo.gc.ca/).The potential distribution in North America was also modeled as part of the risk assessment. The biological risk assessment concluded that the risk of impact was high in, at least, some parts of Canada, including the southern Great Lakes basin. Possession of live individuals of the Northern snakehead is banned in Ontario and other Canadian provinces (https://www.dfo-mpo.gc.ca/csas). It has been banned in Ontario for nearly two decades and in that time no populations have become established in Ontario waters and in the Great Lakes - in spite of 1) highly suitable habitat in the Ontario watershed especially around Lake Ontario, which would be at risk due to the more intense live fish trade around the Toronto area, and 2) scores of individual discoveries of live Northern snakehead in the American states bordering the Great Lakes (and one specimen found in Lake Michigan) during the early 2000s (Ricciardi pers. comm.).

Successsful case study 2: Clubbed or Stalked sea squirt (*Styela clava)* in New Zealand Following the passing of the Biosecurity Act in New Zealand in 1993, there was a heightened realisation that growth in trade and tourism has increased the chances of new IAS arriving. These realisations have led to a more systematic and wide-ranging approach to protecting New Zealand, including more attention to marine biosecurity. Biosecurity New Zealand have an alert system for raising awareness about the introduction of the Clubbed sea squirt as part of their 'Know the Enemy' series. In October 2005 this invasive sea squirt was discovered in Auckland's Viaduct Basin and in Lyttelton Harbour. It was found soon after on the hull of a vessel that had sailed from Auckland to Picton, and in the Hauraki Gulf and Northland. Eradication seems unfeasible and control of the organism focuses on educating the public to report new incursions and encouraging boat owners to keep their vessels and equipment clean. The Minstry for Primary Industries (MPI) has relased an informative and pictorial information leaflet on spread prevention with a primary focus on economic impacts, stating that Clubbed sea squirt poses a threat to New Zealand's aquaculture industry with its ability to blanket oyster and mussel lines, and competing for space and food. The New Zealand marine biosecurity porthole states the species is under management.

Successful case study 3: Border clearance for yachts and other recreational vessels entering New Zealand The communication on biosecurity actions to restrict entry of marine IAS in New Zealand is a world class gold standard for informing boat owners that all vessels arriving into the country must have a clean hull and niche areas. They must also plan the point of first arrival, make sure they prepare their vessel, meet the biofouling and ballast water and notify the customas and the MPI. Vessels visiting New Zealand from another country must ensure they meet the requirements of the Craft Risk Management Standard for Biofouling (CRMS) prior to arrival. Inspections are rigourous involving customs

and quaranting officers, and the main communication issued following an inspection is the declaration for biosecurity clearance. The entire process involves effective communication before, during, and following entry to New Zealand within a regulatory framework where state officials and boat owners have responsibilities. If the latter was in any doubt before the process, all skippers will certainly be biosecurity-aware following successful landing to New Zealand. This example closes the loop between clear communications and effective governance – the stakeholder knows what to expect, has to follow the regulations, and is then inspected to ensure that biosecurity measures are in place before being admitted to New Zealand. The boat is registered to allow clear passage around New Zealand.

Unsuccessful case studies on theprevention of Zebra mussel in the Great Western Lakes, Ireland and in the Western States of the USA Once introduced to a landmass, the prevention of Zebra mussel spread has been largely unsuccessful, despite communication and awareness programmes. The main pathway of spread is *via* recreational angling (see previous section), with juvenile and adult Zebra mussel hitchhiking on boat hulls, or attached to entrained weed or angling equipment. This spread is preventable when biosecurity measures such as check, clean and dry are taken in an appropriate and sustained manner. Relevant communication campaigns have been undertaken in Ireland, the UK, North America and elsewhere to prevent spread of Zebra mussel, once established. Two examples where communication has been unsuccessful are the spread of Zebra mussel to Ireland's Great Western Lakes and in the introduction to waterbodies west of the Rocky Mountains in the United States of America. **Unsuccessful case study 1: Prevention of Zebra mussel in the Great Western Lakes, Ireland** Following the establishment of Zebra mussel in the Shannon-Erne system in the early 1990s and the subsequent spread to a hub of nearby lakes used for recreational angling, Zebra mussel continued to expand their range in Ireland by overland transport of angling boats to other catchments (Minchin and Moriarty 1998; Lucy *et al*. 2005; Millane *et al*. 2008). By the early 2000s the number of infested popular angling lakes was growing and moving closer geographically to the Great Western Lakes, globally renowned wild Brown trout fisheries. In 2005, a campaign, namely the 'Western Region Zebra Mussel Control Initiative' was established by Galway County Council, with the support of many agencies in the Western River Basin District, to prevent spread of Zebra mussel to Loughs Corrib, Mask, Carra and Conn, and a Zebra mussel prevention officer was appointed to co-ordinate the work. Unfortunately, the campaign was unsuccessful, despite the energy and support provided by many organisations, including the Western Regional Fishery Board (now IFI) and the Heritage Council, for a public awareness campaign that included stakeholder meetings, school outreach programmes, leaflets, bumper stickers and the placing of 123 warning signs at infested and uninfested lake sites. By 2006, Zebra mussel were discovered in Lough Conn and by 2007 and 2009 in Loughs Corrib and Mask respectively, but not in Lough Carra. Probably there are ecological reasons why this invasive species has not established there as it is unlikely to have been protected by biosecurity measures that have failed elsewhere. Further investigation of their absence in Lough Carra is warranted.

Zebra mussel were the first high profile aquatic invasive species to arrive in Ireland in the 1990's before the internet became widespread in use. Despite the support of a dedicated resource, multi-agency support and varied methods of biosecurity dissemination, the campaign failed and Zebra mussel continue to spread in lakes suited to their ecology. The EPA has acknowledged that public information and biosecurity campaigns have not halted the spread of Zebra mussels in Ireland (Tierney *et al.* 2015). This failure is also compounded by lack of legislation and enforcement.

Signage to stop the spread of Zebra mussel on a lake in the west of Ireland.

Unsuccessful case study 1: Prevention of Zebra mussel in the Western States of the USA In the United States, Zebra mussel were established in the Great Lakes by 1986 and are now widespread in the Great Lakes and all the major river drainages east of the Rocky Mountains (USGS Map). The closely related Quagga mussel were discovered in the Erie Canal and Lake Ontario in 1991. The 100th Meridian Initiative, drafted in 1998, is a cooperative effort between local, state, provincial, regional, tribal, and federal agencies to prevent the westward spread of Zebra/Quagga mussel and other aquatic nuisance species in North America. As one of its seven goals, it prioritises information and education for the public about the biology, impact, and pathways for spreading Zebra mussel and actions they can take to prevent their spread. Information is disseminated through numerous means including print and electronic news coverage, public service announcements, billboards, articles in boating and fishing magazines, talks to sportsmen clubs, and posters and brochures placed at marinas and boat landings, and brochures packaged with boating and fishing licences. For many years, no Zebra or Quagga mussel were discovered west of the Rockies but in 2007 Quagga mussels were discovered in Lake Mead (Arizona) and within months their shells were washing up on the shores of Lake Mohave (borders Arizona, California and Nevada) and Lake Havasu (borders California and Arizona). In southern California, Quagga mussel have been found in several reservoirs that are part of the Metropolitan Water District, which brings Colorado River water to southern California, supplying the region with half of its drinking water. In 2008, Zebra mussels were discovered in the San Justo Reservoir in central California.

Overland transport of boats fouled by Zebra and Quagga mussel most likely aided their transport across the Rockies, indicating that education and outreach efforts were not effective. There is no doubt that education and awareness needs to be supported by legislation, monitoring and enforcement. The 100th Meridian Initiative, while a well-resourced and long-standing campaign, with communication as a focal part of the overall effort, also includes boat inspections and surveys. It has not, however managed to prevent the spread of Zebra/Quagga mussel to Arizona, California or Nevada, although other western states (e.g. Washington and Oregon) have not yet recorded Zebra mussel in the wild. On March 8th 2021, a citizen's report of an invasive Zebra mussel found in an aquarium moss package present in a pet store prompted a US Geological Survey expert on invasive aquatic species to trigger nationwide alerts that have led to the discovery of the destructive shellfish in pet stores in at least 21 states, from Alaska to Florida.

5. Recommendations for changes to policy and legislation and biosecurity management for IAS in Ireland

Substantial increases in targeted and sustainable measures in the areas of IAS and specifically biosecurity management in Ireland need to be delivered if a realistic barrier to the movement of these harmful species into and within the island is to be established. While the need for focused attention on biosecurity has long been recognised by different arms of government (e.g. Department of Housing, Planning and Local Government in its River Basin Management Plan for Ireland 2018-2021; National Biodiversity Action Plan 2017-2021), the same government is providing no direct leadership in the rollout of practical measures or guidance to stop the introduction and spread of IAS.

There is an urgent need to record and report the damage costs of IAS to ensure that the limited finances available are channelled into early-invasion stage management (i.e. biosecurity) rather than post-invasion control. Indeed, post-invasion management has been found to be 25-times more costly that pre-invasion management (Diagne *et al.* 2020). More economic modelling, accessing relevant stakeholder datasets, is required to allow for annual budget projections for IAS management in Ireland.

While the EU Regulation has the capacity to effectively tackle IAS problems across Europe, the lack of dedicated funding to individual MS to help implement this legislation will result in its failure. The EU must be encouraged to provide at least some funding, or other appropriate inducement, to individual MS for the implementation and enforcement of this important legislation. On a similar vein, the Irish government must appreciate the costs being incurred and the damage being caused by IAS in Ireland, and provide sufficient resources to the competent authority (currently NPWS) to effectively manage IAS issues and to develop and adopt coherent biosecurity protocols for all state and semi-state bodies. This will be particularly important when the results from the strategic review on NWPS and the new national legislation for IAS in Ireland are both published later in 2021.

For reasons outlined in Section 1.5, a well resourced single lead Division for IAS and biosecurity, operating under the aegis of NPWS, should be established in Ireland. This IAS Division would liaise closely and collaborate with responsible agencies in NI to help prevent the introduction and spread of IAS on the island of Ireland. A primary function of this IAS Division would be to develop a National Strategy for IAS Management. To support this IAS Division, an All-Ireland Invasive Alien Species Forum or steering group, similar to the Invasive Species Ireland project that operated from 2006 to 2013, should be established. This could operate in tandem with the GB Non-native Species Secretatiat, which successfully coordinates the approach to IAS in Great Britain.

If a lead IAS Division in Ireland is to be established, a Section within it that has responsibility for biosecurity management must be a central component. This Section must be suitably resourced to enable it to develop a coherent and coordinated national approach to biosecurity, to develop appropriate policy, strategy and action

plans, and to facilitate communication and collaboration between government departments, scientific and environmental institutions, NGOs, stakeholders and the public. It would also lead collaboration on biosecurity matters with responsible agencies in NI. In New Zealand, the federal government assigned accountability to a single ministry (Ministry for Primary Industries, MPI) for the end-to-end management of the biosecurity system in the country, and the MPI coordinates other agencies to ensure nationally consistent biosecurity management (Champion 2018).

Future biosecurity management to restrict the entry and spread of IAS in Ireland must be informed by the development of a National Biosecurity Strategy for IAS, to operate alongside the National IAS Management Strategy. This would draw heavily on existing biosecurity policy, strategy and experience in other countries, particularly the likes of New Zealand where the operation of good biosecurity practice from key stakeholders to the individual members of the public has virtually stopped the introduction and spread of IAS within this country. While the new IAS Division (or NPWS, as the current regulator) would lead in the production of such a comprehensive Strategy, it will be important that active and committed support is given by government departments that are in any way connected to IAS or affected by them (see Table 1). The involvement of a wide diversity of stakeholders and the public in the formulation of the Strategy will improve its scope and, presumably, result in more wholesome buy-in when the Strategy is being rolled out.

This Strategy must require government departments and agencies in Ireland to develop and implement biosecurity protocols for their staff, consultants and stakeholder. It will be important that all government departments provide biosecurity training for their staff, in compliance with Target 4.4 of the current National Biodiversity Action Plan (2017 – 2021). In addition, a range of comprehensive IAS/biosecurity training courses that are dedicated to the specific needs of different stakeholder groups should be developed. Blended training (to include online and hands-on elements) would probably provide the best option, spearheaded through third level institutions. As part of this initiative, it is imperative that our Customs services are provided with sufficient resources, training and support to enable them to provide an effective barrier to the movement of IAS into the country. Further, organisations charged with the management or maintenance of water or watercourses in Ireland need training and resourcing to integrate IAS into their day-to-day work programmes.

A formal cooperative mechanism for joined-up working across government departments and agencies, north and south of the border, is required to effectively manage IAS and biosecurity in Ireland. In the past, IFI operated a dedicated Invasive Species Section within its Research Department (see Section 1.4). This team was trained and resourced to react to new IAS incursions and to help manage the spread of established freshwater and riparian IAS. This proactive management of IAS was extremely successful and provides an example of what should be made available on a national scale and through a co-ordinated, cross-agency and cross-border approach.

Horizon scan exercises in Ireland and Geat Britain have clearly identified those IAS that are most likely to be introduced to Ireland in the coming years. Clear, unambiguous Contingency Plans to deal with these species

must be prepared and made available to personnel that are trained in their implementation. In addition, work on the preparation of Pathway Action Plans (PAP) for priority IAS, in addition to just IAS of Union concern, must be upscaled by the competent authority or its consultants. Also, Management Plans for IAS that are already established in the country should be compiled, supported by the best information available from research and practice on IAS control conducted in Ireland and abroad.

In New Zealand, deemed by Simberloff (2014) to have a world-leading biosecurity system, particularly in the area of IAS detection at points of entry to the country and early detection and rapid response, the strategic focus of proactive IAS management is scientific research driven, with direct uptake of research findings by management and policy agencies (Champion 2018). Targeted research can provide tools for effective control and eradication of IAS, as illustrated by our recent EPA report. We need to further research what is best biosecurity practice abroad and determine how and why it works in these countries. It would be worthwhile to liaise closely with countries where it is acknowledged that biosecurity is effectively operated and to engage with the main architects of these campaigns (e.g. NZ, Australia, Norway, South Africa).

Research requirements in Ireland include new and innovative biosecurity approaches to control the spread and management of IAS that are already present in the country. A number of peer-reviewed scientific papers have recently been published that focus directly on this topic. In addition, tool boxes for IAS eradication, control and management have been partially developed (Coughlan *et al*. 2019a,b; 2020a,b,c,d). This formative research work, however, needs to be field tested and brought into practical use to provide rapid reaction tools for dealing with new IAS introductions and the spread of species already established in the country.

As part of any National Biosecurity Strategy, it will be important to develop and actively promote biosecurity campaigns (i.e. suitable logos and messages, similar to “Check Clean Dry”, as currently used in New Zealand and the UK) that will generate and promote public awareness. One shortfall of the current ‘Check Clean Dry’ campaign (and one that is acknowledged by the UK) is the lack of consideration for the need to disinfect, particularly to prevent the spread of parasites and pathogens (e.g. Salmon fluke, Crayfish plague, rosette disease). A new campaign may simply amend the popular ‘Check Clean Dry’ campaign to include the word Disinfect before Dry (Lucy *et al.* 2021), or a new and more ambitious Irish campaign could be developed. An example of a novel Irish biosecurity campaign emerged from a major Irish coarse angling fishery, Lough Muckno in Co. Monaghan. Here, the local angling club introduced a policy that no anglers could enter competitions or fish at this venue if they did not disinfect their landing- and keep-nets before fishing. This became the ‘No Dip No Draw’ campaign and it proved to be very successful in keeping IAS out of this large and popular lake fishery. It is suggested that this, or similar campaigns, could be extended to other watercourses throughout the country.

The development of biosecurity protocols, codes of practice and best practice guidelines that are tailored to the specific requirements of different stakeholders, IAS and habitats is vitally important. These protocols and

procedures must be produced in such a manner that they are accessible, interpretable, and easily implemented. Then, they must be adopted by the stakeholders for which they were produced.

We need to establish a legally binding national biosecurity declaration form for IAS, to be completed upon entry to the country. We recommend that disinfection certificates for goods entering the country or over the border (e.g. earth moving and other works' machinery, cruisers) should be mandatory. Disinfection certificates for fishing boats moving from one watercourse to another within the country should also be mandatory.

All sports, hunting, angling and other recreational equipment entering the country should accompanied by an up-to-date certificate of cleaning/disinfection. In tandem, cleaning and disinfection facilities at or close to points of entry to the country should be provided, with an amnesty bin for contaminated or prohibited items.

Alongside the above, it will be important to develop and promote professionally produced information/education campaigns to create awareness among stakeholders and the public of the existence, adverse impacts and costs/legal implications associated with IAS. These will highlight the importance of good biosecurity practice to prevent the introduction and spread of IAS. A wide range of platforms are currently available to disseminate material, including social media, apps, advertising (in specialist magazines, local and national print media, national and local radio and television), dedicated radio and television programmes, nationwide talk/lecture series, local and regional demonstrations/workshops, practical biosecurity demonstrations at major events in Ireland (e.g. Bloom, Ploughing Championship, Liffey descent).

MPI in New Zealand have created a Pest and Disease hotline telephone number for the public to report any new or unusual organisms or disease symptoms (e.g. Crayfish plague), which has met with considerable success in respect of early IAS detections and new incursions. IFI has a hotline number that is primarily used for fisheries enforcement but can also be used to report the presence of IAS. It would be worth having a similar national hotline number for reporting IAS or biosecurity issues.

In order to detect new IAS incursions at the earliest possible stage, the MPI conducts annual surveillance surveys in some of New Zealand's busiest ports and marinas, during which up to 2,000 samples are taken for analysis. Between 2010 and 2015, 33 species new to New Zealand were recorded, including one notifiable organism (Wood *et al.* 2017). Likewise, invasive freshwater plant surveys are also undertaken annually in many of New Zealand's regions, particularly those with a substantial risk of invasive plant incursion. As a consequence of early detections, several invasive alien plant species have been identified and successfully managed (Champion and Wells 2008). It is recommended that the competent authority for IAS in Ireland should have or enlist a team of scientists whose role it would be to conduct similar surveillance monitoring.

Development of a suite of practical, easy-to-use, environmentally safe, and cost-effective cleaning and disinfection tools (e.g. portable Disinfection Bags, Disinfection Kit Boxes, permanent Disinfection Stations used at some major angling venues in Ireland, portable canoe/kayak cleaning chutes, among others) is required for use by a broad spectrum of stakeholder groups (see also Appendix III).

CONCLUSIONS

Invasive Alien Species are currently causing enormous damage to our environment and economy, and this is highly likely to continue in the absence of effective and timely interventions. There will almost certainly be new IAS incursions into Ireland in the near future in the absence of a focussed biosecurity strategy. The extortionate current and future economic costs of IAS are clear and thus substantial research and development spending is urgently required and is economically justified. Indeed, this report highlighted that resources are critically lacking in the efforts to tackle IAS and this is the root cause of current IAS problems in Ireland. This commissiond research has produced 10 key recommendations that, if implemented, promise to significantly reduce IAS impacts across our environment and society. With international trade, climate change and new and emerging IAS pathways interacting, the country faces irreversible damages if decisive and targeted actions are not taken in the coming years and sustained for the foreseeable future. They key recommendations are to:

1. Establish a suitably resourced, single lead Division that is responsible for Invasive Alien Species management in Ireland, working under the aegis of the National Parks and Wildlife Service (NPWS).
2. Establish an All-Ireland IAS Forum.
3. Develop a national Biosecurity Strategy for Ireland.
4. Provide appropriate resources, training and support in relation to IAS for our national Customs services at ports/entry points throughout Ireland.
5. Produce comprehensive Management Plans for IAS currently in Ireland, along with Contingency Plans for IAS expected to arrive in the future (based on horizon scan exercises).
6. Develop a surveillance programme to regularly monitor water bodies for the presence and status of IAS.
7. The new IAS legislation for Ireland that will come into force in 2021 must be implemented and enforced by the responsible agency.
8. Develop national IAS education and awareness programmes in Ireland.
9. Harness community involvement and support to ensure the long-term sustainability of national and local IAS and biosecurity programmes.
10. Significantly increase the level of research and management funding into IAS.

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APPENDIX I.

Aquatic and semi-aquatic species introduced into Ireland; species name, taxonomic group, common name (if available) with hyperlink, and reference (n=201). Green=naturalised/not invasive; Orange=potentially invasive; Red=invasive. Adapted from references in last column. See Appendix III for actual and potential biosecurity, eradication, control or management methods.

Species	Taxonomic group	Common Name	Source
1.Abramis brama	Fish	Common Bream	Minchin
2.Acanthocephalus anguillae	Worm (parasite)	Thorny-headed worms	Minchin
3.Acanthocephalus lucii	Worm (parasite)	Thorny-headed worms	Minchin
4.Acorus calamus	Plant	Sweet Flag	Minchin
5.Aerococcus viridans	Bacteria	*Aerococcus*	Minchin
6.Aix galericulata	Bird	Mandarin Duck	NBDC
7.Alexandrium minutum	Algae	*A. minitum*	GISD
8.Alexandrium tamarense	Algae	*A. tamarense*	Minchin
9.Alopochen aegyptiacus	Bird	Egyptian Goose	NBDC
10.Alosa sapidissima	Fish	American Shad	Minchin
11.Ameiurus melas	Fish	Black bullhead	Minchin
12.Anguillicoloides crassus	Worm (parasite)	Swim-bladder nematode	NBDC
13.Antithamnion densum	Algae	*A. densum*	Minchin
14.Antithamnionella spirographidis	Algae	*A. spirographidis*	Minchin
15.Antithamnionella ternifolia	Algae	*A. ternifolia*	NBDC
16.Aphanomyces astaci	Algae	Crayfish Plague	GISD
17.Aponogeton distachyos	Plant	Cape-pondweed	Minchin
18.Asparagopsis armata	Algae	Harpoon weed	Minchin
19.Austropotamobius pallipes	Crustacean	White-clawed crayfish	Minchin
20.Azolla filiculoides	Algae	Water fern	NBDC
21.Balanus amphitrite	Crustacean	Striped Barnacle	Minchin
22.Balanus improvisus	Crustacean	Bay Barnacle	NBDC
23.Bankia fimbriata	Mollusc	Shipworm	Minchin
24.Barbatula barbatula	Fish	Stone loach	Minchin
25.Bdellocephala punctata	Worm	*B. punctata*	Minchin
26.Bonamia ostreae	Protozoa	Bonamiosis	Minchin
27.Bonnemaisonia hamifera	Algae	*B. hamifera*	Minchin
28.Botrylloides violaceus	Tunicate	Violet tunicate	NBDC
29.Brachidontes exustus	Mollusc	Scorched mussel	Minchin
30.Branchiura sowerbyi	Worm	Tubificid worm	Minchin
31.Branta canadensis	Bird	Canada Goose	GISD
32. Bufo bufo	Toad	Common toad	Anecdotal
33.Bugula neritina	Bryozoan	Common bugula	NBDC

34.Caligus pageti	Crustacean	*Caligus*	Minchin
35.Calyptraea chinensis	Mollusc	Chinese Hat Snail	Minchin
36.Caprella mutica	Crustacean	Japanese skeleton shrimp	NBDC
37.Carassius auratus	Fish	Goldfish	NBDC
38.Caryophyllaeides fennica	Worm (parasite)	*C. fennica*	Minchin
39.Caryophyllaeus laticeps	Worm	Clove worm	Minchin
40.Ceratophyllum submersum	Plant	Soft hornwort	Minchin
41.Chelicorophium curvispinum	Crustacean	Caspian mud shrimp	Minchin
42.Chelydra serpentina	Reptile	Common snapping turtle	NBDC
43.Clymenella torquata	Worm	Bamboo worm	Minchin
44.Codium fragile ssp. tomentosoides	Algae	*C. f. tomentosoides*	GISD
45.Colpomenia peregrina	Plant	*C. peregrina*	Minchin
46.Conchophthirus acuminatus	Algae	*C. acuminatus*	Minchin
47.Corbicula fluminea	Mollusc	Asian Clam	NBDC
48.Cordylophora caspia	Cnidarian	Freshwater hydroid	Minchin
49.Corella eumyota	Sea Squirt	Orange-tipped Sea Squirt	Minchin
50.Corophium multisetosum	Crustacean	Mud shrimp	Minchin
51.Coscinodiscus wailesii	Algae	*C. wailesii*	Minchin
52.Crangonyx pseudogracilis	Crustacean	American shrimp	Minchin
53.Craspedacusta sowerbyi	Jellyfish	Peach blossom jellyfish	NBDC
54.Crassostrea angulate	Mollusc	Portuguese oyster	Minchin
55.Crassostrea gigas	Mollusc	Pacific oyster	NBDC
56.Crassostrea virginica	Mollusc	Eastern oyster	Minchin
57.Crassula helmsii	Plant	Australian swamp stonecrop	NBDC
58.Crassula tillaea	Plant	Moss pygmyweed	NBDC
59.Crepidula fornicata	Mollusc	Common slipper shell	NBDC
60.Critomolgus actinae	Crustacean (copepod)	*C. actinae*	Minchin
61.Cryptonema hibernica	Red Algae	*C. hibernica*	Minchin
62.Cygnus atratus	Bird	Black Swan	NBDC
63.Cyprinus carpio	Fish	Common carp	GISD
64.Dactylogyrus vastator	Worm (parasite)	*D. vastator*	Minchin
65.Daphnia atkinsoni	Crustacea	*D. atkinsoni*	Minchin
66.Dendrostrea frons	Mollusc	Frond oyster	Minchin
67.Diadumene lineata	Cnidaria	Orange-striped sea anemone	Minchin
68.Didemnum vexillum	Tunicate	Carpet sea squirt	NBDC
69.Didymosphenia geminata	Diatom	Didymo	GISD
70.Diphyllobothrium latum	Worm (parasite)	*Diphyllobothrium*	Minchin
71.Diplozoon paradoxum	Worm (parasite)	*D. paradoxum*	Minchin

72.Dreissena polymorpha	Mollusc	Zebra mussel	GISD
73.Dugesia tigrina	Worm	*D. tigrina*	Minchin
74.Egeria densa	Plant	Leafy elodea	NBDC
75.Elminius modestus/Austrominius modestus	Crustacea	Australasian barnacle	GISD
76.Elodea canadensis	Plant	Canadian pondweed	NBDC
77.Elodea nuttallii	Plant	Nuttall's waterweed	NBDC
78.Ergasilus gibbus	Crustacea	*E. gibbus*	Minchin
79.Eriocheir sinensis	Crustacea	Chinese mitten crab	GISD
80.Erpobdella testacea	Leech	*E. testacea*	Minchin
81.Esox lucius	Fish	Northern Pike	GISD
82.Fallopia japonica	Plant	Japanese knotweed	Present authors
83.Ferrisia wautieri	Mollusc	Wautier's limpet	Minchin
84.Ficopomatus enigmaticus	Polychaete worm	tubeworm	GISD
85.Gammarus pulex	Crustacea	River Shrimp	NBDC
86.Gammarus tigrinus	Crustacea	American tiger shrimp	NBDC
87.Gobio gobio	Fish	Gudgeon	Minchin
88.Gracilaria multipartata	Red algae	*G. multipartata*	Minchin
89.Groenlandia densa	Plant	*G. densa*	Minchin
90.Gunnera tinctoria	Plant	Giant rhubarb	Present authors
91.Haliotis discus	Mollusc	Japanese abalone	Minchin
92.Haliotis tuberculata	Mollusc	Green ormer/ European edible abalone	Minchin
93.Hemimysis anomala	Crustacea	Bloody red shrimp	NBDC
94.Heracleum mantegazzianum	Plant	Giant hogweed	GISD
95.Herrmannella duggani	Crustacea	*H. duggani*	Minchin
96.Heterolaophonte hamondi	Crustacea	*H. hamondi*	Minchin
97.Heterosigma akashiwo	Algae	Red tide	Minchin
98.Heterosiphonia japonica	Algae	*H. japonica*	Minchin
99.Hirudo medicinalis	Leech	Medicinal leech	Minchin
100.Homarus americanus	Crustacea	American Lobster	Minchin
101.Hottonia palustris	Plant	Water violet	Minchin
102.Hucho hucho	Fish	Huchen	Minchin
103.Hydrilla verticillata	Plant	*Hydrilla*	Minchin
104.Hydrocotyle ranunculoides	Plant	Floating pennywort	NBDC
105.Ictalurus catus	Fish	White catfish	Minchin
106.Isochrysis aff. galbana	Hapto-phyte	*I. galbana*	Minchin
107.Impatiens glandulifera	Plant	Himalayan balsam	Present authors
108.Isognomon radiata	Mollusc	*I. radiata*	Minchin

109.Juncus compressus	Plant	Round-fruited rush	Minchin
110.Juncus planifolius	Plant	Broadleaf Rush	Minchin
111.Karenia mikimotoi	Algae	*K. mikimotoi*	Minchin
112.Labyrinthula zosterae	Algae	*L. zosterae*	Minchin
113.Lagarosiphon major	Algae	Curly waterweed	GISD
114.Lemna minuta	Plant	*L. minuta*	NBDC
115.Leuciscus leuciscus	Fish	Common Dace	NBDC
116.Ligula intestinalis	Worm (parasite)	*L. intestinalis*	Minchin
117.Limnoria quadripunctata	Crustacea	Gribble	Minchin
118.Lophopus crystallinus	Bryozoan	Bellflower animal	Minchin
119.Ludwigia grandiflora	Plant	Water primrose	NBDC
120.Luronium natans	Plant	*L. natans*	Minchin
121.Lysichiton americanus	Plant	American skunk cabbage	Minchin
122.Marsupenaeus japonicus	Crustacea	Kuruma shrimp	Minchin
123.Martesia striata	Mollusc	Striate martesia	Minchin
124.Megabalanus tintinnabulum	Crustacea	Large barnacle	Minchin
125.Mercenaria mercenaria	Mollusc	Hard clam	Minchin
126.Molgula manhattensis	Sea Squirt	Sea Grapes	Minchin
127.Monocorophium insidiosum	Crustacea	*M. insidiosum*	Minchin
128.Monocorophium sextonae	Crustacea	*M. sextonae*	Minchin
129.Muceddina multispinosa	Crustacea	*M. multispinosa*	Minchin
130.Mya arenaria	Mollusc	Sand gaper	Minchin
131.Myicola ostreae	Crustacea	*M. ostreae*	Minchin
132.Myocastor coypus	Mammal	Coypu	NBDC
133.Myriophyllum aquaticum	Plant	Parrot's feather	NBDC
134.Mytilicola intestinalis	Crustacea	Mussel red worm	Minchin
135.Mytilicola orientalis	Crustacea	Oyster redworm	NBDC
136.Mytilus galloprovincialis	Mollusc	Mediterranean mussel	GISD
137.Neosiphonia harveyi	Plant	*N. harveyi*	Minchin
138.Neovison vison	Mammal	American mink	NBDC
139.Nuphar pumila	Plant	*N. pumila*	Minchin
140.Nymphoides peltata	Plant	Yellow floating heart	NBDC
141.Odontella sinensis	Algae	Chinese diatom	Minchin
142.Oncorhynchus gorbuscha	Fish	Pink salmon	Minchin
143.Oncorhynchus mykiss	Fish	Rainbow trout	GISD
144.Ondatra zibethicus	Mammal	Muskrat	NBDC
145.Ophryoglena hemophaga	Algae	*O. hemophaga*	Minchin
146.Ostracoblabe implexa	Fungus	Shell disease	Minchin
147.Ostrea edulis	Mollusc	European oyster	GISD

148.Ostrea equestris	Mollusc	Horse oyster	Minchin
149.Oxyura jamaicensis	Bird	Ruddy duck	GISD
150.Paralaeospira malardi	Worm	*P. malardi*	Minchin
151.Patinopecten yessoensis	Mollusc	Japanese scallop	Minchin
152.Perca fluviatilis	Fish	Perch	GISD
153.Phallusia mamillata	Sea Squirt	*P. mammillata*	Minchin
154.Phoxinus phoxinus	Fish	Eurasian minnow	GISD
155.Physella acuta	Mollusc	Acute or lateritic bladder snail	NBDC
156.Physella gyrina	Mollusc	Tadpole bladder snail	Minchin
157.Pileolaria militaris	Worm	*P. militaris*	Minchin
158.Pilumnoides inglei	Crustacea	*P. inglei*	Minchin
159.Planorbarius corneus	Mollusc	*Great ramshorn*	Minchin
160.Pollicipes pollicipes	Crustacea	Goose barnacle	Minchin
161.Polysiphonia brodiei	Algae	*P. brodiei*	GISD
162.Polysiphonia harveyi	Algae	*P. harveyi*	NBDC
163.Polysiphonia subtillissima	Algae	*P. subtillissima*	Minchin
164.Pomphorhynchus laevis	Worm (parasite)	Spiny headed worm	Minchin
165.Pontederia cordata	Plant	Pickerel weed	Minchin
166.Porcellidum ovatum			Minchin
167.Posthodiplostomum cuticola	Worm (parasite)	Blackspot	Minchin
168.Potamopyrgus antipodarum	Mollusc	New Zealand mudsnail	NBDC
169.Potamothrix moldaviensis	Worm	*P. moldaviensis*	Minchin
170.Potamothrix vejdovskyi	Worm	*P. vejdovskyi*	Minchin
171.Pseudodactylogyrus anguillae	Worm (parasite)	*P. anguillae*	Minchin
172.Pseudodactylogyrus bini	Worm (parasite)	*P. bini*	Minchin
173.Riccia rhenana	Plant	Pond crystalwort	NBDC
174.Ruditapes philippinarum	Mollusc	Manila clam	NBDC
175.Rutilus rutilus	Fish	Roach	GISD
176.Sagittaria rigida	Plant	Canadian arrowhead	Minchin
177.Sargassum muticum	Algae	Wireweed	GISD
178.Scardinius erythrophthalmus	Fish	Rudd	GISD
179.Schizoporella unicornis	Plant	Sea mat	GISD
180.Skeletonema subsalsum	Algae	*S. subsalsum*	Minchin
181.Spartina anglica	Plant	Common cordgrass	NBDC
182.Spartina pectinata	Plant	*S. pectinata*	Minchin
183.Spartina x townsendii	Plant	Townsend's cordgrass	Minchin
184.Sparus aurata	Fish	Gilthead seabream	GISD
185.Squalius cephalus	Fish	Chub	NBDC
186.Stenopelmus rufinasus	Insect	*S. rufinasus*	NBDC

187.Stratiotes aloides	Plant	Water soldier	Minchin
188.Styela clava	Sea Squirt	*S. clava*	GISD
189.Taxodium distichum	Plant	Bald cypress	NBDC
190.Telmatogeton japonicus	Insect	*T. japonicus*	Minchin
191.Terebella lapidaria	Worm	*T. lapidaria*	Minchin
192.Teredo navalis	Mollusc	Great shipworm	Minchin
193.Tetracotyle percafluviatilis	Worm (parasite)	*T. perca fluviatilis*	Minchin
194.Tinca tinca	Fish	Tench	GISD
195.Trachemys scripta	Turtle	Pond slider	NBDC
196.Tylodelphys clavata	Worm (parasite)	*T. clavata*	Minchin
197.Tylodelphys podicipina	Worm (parasite)	*T. podicipina*	Minchin
198.Ulva californica	Plant	*U. californica*	Minchin
199.Undaria pinnatifida	Algae	Asian kelp	NBDC
200.Venerupis philippinarum *Syn:Ruditapes philippinarum*	Mollusc	Japanese carpet shell	Minchin
201.Viviparus viviparus	Mollusc	Common river snail	Minchin

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APPENDIX II.

Horizon scan "Top 40" list of likely new Invasive Alien Species predicted to arrive in Ireland in the next 10 years. (Lucy *et al.* 2020). See Appendix III for actual and potential biosecurity, eradication, control or management methods.

Rank	Species	Common name
1	*Pacifastacus leniusculus*	Signal crayfish
2	*Capreolus capreolus*	Roe deer
3	*Dikerogammarus villosus*	Killer shrimp
4	*Gyrodactylus salaris*	Salmon fluke
5	*Hesperibalanus fallax*	Warm-water barnacle
6	*Hydrocotyle ranunculoides*	Floating pennywort
7	*Dreissena rostriformis bugensis*	Quagga mussel
8	*Caulacanthus okamurae*	Pom-pom weed
9	*Eriocheir sinensis*	Chinese mitten crab
10	*Pseudorasbora parva*	Topmouth gudgeon; Stone moroko
11	*Ondatra zibethicus*	Muskrat
12	*Psittacula krameri*	Ring-Necked parakeet
13	*Agrilus planipennis*	Emerald ash borer
14	*Agrilus anxius*	Birch borer
15	*Ensis directus*	American razor-clam
16	*Dikerogammarus haemobaphes*	Demon shrimp
17	*Orconectes limosus*	Spinycheek crayfish
18	*Oncoryhnchus mykiss*	Rainbow Trout
19	*Squalius cephalus*	Chub
20	*Ludwigia grandiflora (+species)*	Water primrose
21	*Microtus agrestis*	Field vole
22	*Cochlicella barbara*	Pointed snail
23	*Procyon lotor*	Raccoon
24	*Tamias sibiricus*	Siberian chipmunk
25	*Hemigrapsus takanoi*	Brush-clawed shore crab
26	*Thymallus thymallus*	Grayling
27	*Barbus barbus*	Barbel
28	*Sander lucioperca*	Zander; Pikeperch
29	*Orconectes virilis*	Virile crayfish
30	*Obama nungara*	Flatworm
31	*Myriophyllum heterophyllum*	American water-milfoil
32	*Hylastes ater*	Black pine bark beetle
33	*Salvelinus fontinalis*	Brook trout; Brook charr; Sea trout
34	*Astacus astacus*	Noble Crayfish; Broad-fingered crayfish
35	*Celtodoryx ciocalyptoides*	sponge
36	*Hemigrapsus sanguineus*	Asian shore crab
37	*Myiopsitta monachus*	Monk parakeet; Grey-headed parakeet
38	*Orconectes rusticus*	Rusty crayfish
39	*Microtus arvalis*	Orkney vole
40	*Threskiornis aethiopicus*	Sacred Ibis; African Sacred Ibis

APPENDIX III.

Control/eradication and/or biosecurity measures, potential and actual, that may be used against various types of Invasive Alien Species, notes on their use and references.

Control/Eradication/ Biosecurity Measure	**Invasive Alien Species Types**	**Notes**	**Reference**
Glyphosate/Syneco	Riparian plants eg Himalayan balsam; macrophytes eg water primrose	Spraying/injection; risk of non-target effects	EPA Report Lucy *et al.* 2021
Rotenone	Fish	Risk of non-target effects e.g. insects	Dalu *et al*. 2015
Electrofishing/netting	Fish	Risk of non-target effects eg native fish	Caffrey *et al*. 2008; Caffrey *et al*. 2018
Dry ice (solid nitrogen)	Bivalves	Exposed, buried and underwater effective eg Asian clam; limited non-target effects	EPA Report Lucy *et al.* 2021
Heat torch	Bivalves	Exposed effective; eg Asian clam	EPA Report Lucy *et al.* 2021
Shooting	Turtles/birds	Effective and targeted; e.g. red-eared sliders, ruddy duck	GB Non-native Species Secretariat
Virkon Aquatic	Bivalves (small); parasites/disease (eg crayfish plague)	Broadly effective on some animals and plants	EPA Report Lucy *et al.* 2021
Zequanox	Zebra mussels	Effective at small scale	Meehan *et al*. 2013, 2014
Fumigation	Insects	Not routinely used in Ireland, used (e.g. New Zealand) in shipping containers	Bell (2000)
Check, Clean Dry Hot water spray Steam	Attached animals plants e.g. bivalves, macrophytes	For biosecurity of e.g. vessels, not control or eradication	Coughlan *et al.* 2020; Bradbeer *et al.* 2020
Freezers	Attached animals plants eg bivalves, macrophytes	Handy for e.g. sampling equipment, nets, boots	Inland Fisheries Ireland, DAERA Best Practice
Ballast water exchange	Zooplankton	Not routine in UK/Ireland	Hewett *et al*. 2006
Detection dogs	Zebra mussels,	Not adopted in UK/Ireland	DeMatteo *et al*. 2019
Quarantine	Range of animals, plants and pathogens	Poorly used in UK/Ireland	Schrader & Unger 2003
Jute matting	Macrophytes e.g. Curly water weed	Effective but expensive	Caffrey *et al.* 2010
Cutting/dredging	Macrophytes e.g. water weed	Can worsen problem due to viable propagule creation	Caffrey *et al.* 2006
Ivermectin/abamectin	Parasites/pathogens	Broadly effective (e.g. fish parasites)	Davies & Rodger (2001)
Molluscicides	Molluscs	Not widely used in UK/Ireland; disease control too (e.g. Africa)	Wang *et al*. (2018)

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