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ORIGINAL PAPER

Horizon scanning for invasive alien species with the potential to threaten biodiversity and human health on a Mediterranean island

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Abstract Invasive alien species (IAS) are one of the major drivers of change that can negatively affect biodiversity, ecosystem functions and services and human health; islands are particularly vulnerable to biological invasions. Horizon scanning can lead to

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prioritisation of IAS to inform decision-making and action; its scale and scope can vary depending on the need. We focussed on IAS likely to arrive, establish and affect biodiversity and human health on the Mediterranean island of Cyprus. The scope of the horizon scanning was the entire island of Cyprus. We used a two-step consensus-building process in which experts reviewed and scored lists of alien species on their likelihood of arrival, establishment and potential to affect biodiversity, ecosystems and/or human health in the next 10 years. We reviewed 225 alien species, considered to be currently absent on Cyprus, across taxa and environments. We agreed upon 100 species that constituted very high, high or medium biodiversity risk, often arriving through multiple pathways of introduction. The remaining 125 species were ranked as low risk. The potential impacts on human health were documented for all 225 species; 82 species were considered to have a potentially negative impact on human health ranging from nuisance to disease transmission. The scope of the horizon scanning was the entire island of Cyprus, but the thematic groups also considered the relevance of the top 100 species to the Sovereign Base Areas of Cyprus, given their differing governance. This horizon scan provides the first systematic exercise to identify invasive alien species of potential concern to biodiversity and ecosystems but also human health within the Mediterranean region. The process and outcomes should provide other islands in the region and beyond with baseline data to improve IAS prioritisation and management.

Keywords Consensus approach · Cyprus · Levant · Non-native species · Pathways · Prioritisation

Introduction

The threat from invasive alien species (IAS) as one of the main drivers of biodiversity change is increasing as the number of alien species arriving in countries around the globe is rising with no sign of saturation (Seebens et al. 2017). Islands are particularly vulnerable to biological invasions (Simberloff 1995; Jeschke 2008). Species on islands often persist within small populations with restricted genetic diversity and this, coupled with often limited habitat availability on islands, increases their vulnerability to perturbation by anthropogenic factors, including the introduction of IAS (Russell et al. 2017). Horizon scanning to identify likely future invasions of IAS is, therefore, pivotal for prioritising action and mitigating the negative effects of introduced species on islands. Horizon scanning is an approach used to prioritise the threat posed by potentially new IAS not yet established within a region, and has been seen as an essential component of IAS management with demonstrated net economic and ecological benefits (Keller et al. 2007; Shine et al.

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2010; Caffrey et al. 2014; Roy et al. 2015). The approaches adopted by Roy et al. (2014a) are starting to be applied more widely within Europe (Gallardo et al. 2016; Roy et al. 2015, 2019).

Cyprus provides an interesting context for applying IAS horizon scanning approaches. The Republic of Cyprus as a member of the European Union (EU) is obliged to adopt the Regulation on IAS; however, due to the de facto partitioning of the island, EU law is not applied to the areas where the Government of the Republic does not exercise control. Furthermore, with some exceptions, EU legislation does not apply to the UK Sovereign Base Areas (SBAs) of Akrotiri and Dhekelia, which are not under the sovereignty of the Republic of Cyprus. As a result, the application of measures to protect biodiversity and the establishment of common conservation and management goals across the island is challenging. In particular, the efficacy of measures to manage IAS, including prevention, will depend on initiatives agreed and applied across the entire island. Many such initiatives depend on prioritised lists of alien species (Roy et al. 2014b).

The Mediterranean is a well-known biodiversity hotspot (Myers et al. 2000; Coll et al. 2010), and within that Cyprus harbours important biodiversity, with high degrees of endemism across taxa (Sparrow and John 2016). For example, six out of the 11 wild mammals, excluding the 19 bat species, are considered endemic (Sparrow and John 2016), and the level of endemism for plants (113 species), around 7% of the indigenous flora (Christodoulou 2003; Tsintides et al. 2007), is among the highest in the European Union. IAS are considered one of the major current threats to biodiversity of ecosystems in Cyprus (Hadjikyriakou and Hadjisterkotis 2002; Christodoulou 2003). For example, IAS exert an additional pressure on Cypriot freshwater and salt marsh ecosystems that are already threatened by aquaculture, water extraction, climate change, drainage, the building of dams, and mosquito management, including the use of chemicals or the release of invasive alien mosquitofish *Gambusia* species (Sparrow and John 2016).

Traditionally ecologists and invasion biologists have solely focused on the impacts of IAS on biodiversity and ecosystem functions. The adoption of a more anthropocentric approach, that of ecosystem services (Vilà and Hulme 2017), where biodiversity is considered within the context of human well-being, has highlighted the need to consider the human health impacts of IAS alongside environmental impacts. Most forecasts of the risk of emerging diseases have largely neglected the potential role of alien species (Hulme 2014; Roy et al. 2017; Galil 2018). One Health initiatives (www.onehealthinitiative.com, accessed 08/2018) aim to bring an interdisciplinary approach to the health of people, domestic animals and wildlife, and it has been suggested that such an approach is key to understanding, detecting, and managing the emergence of both alien pathogens,

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pathogens associated with alien species, and their impacts across borders and hosts (Roy et al. 2017). Knowledge on human health impacts is an important consideration for risk assessment and decision-making on IAS, but is currently biased towards only a few species, and impacts are generally poorly understood (Schindler et al. 2015). The impacts of IAS on human health vary from psychological effects, discomfort, nuisance and phobias, to skin irritations, allergies, poisoning, disease and even death (Bayliss et al. 2017; Martinou and Roy 2018).

While recognising that the gaps in knowledge on alien pathogens prohibit systematic consideration across all potential hosts, we recognised an opportunity to consider human health impacts based on expert opinion, even if it is necessary to attribute low confidence to the predictions. Here, for the first time in a horizon scanning exercise, we considered human health effects alongside ecological impacts to derive a list of IAS that are likely to arrive, establish and have an impact on biodiversity, ecosystems and human health within the next 10 years across the entire island of Cyprus.

Methods

Study region

The scope of the horizon scanning was the entire island of Cyprus, but the thematic groups also considered the relevance of the top 100 species to the Sovereign Base Areas of Cyprus, given their differing governance.

Cyprus, located in the Levantine Basin (eastern Mediterranean), is situated 75 km from the Turkish mainland in the north, 150 km from Syria in the east and 380 km from Egypt in the south, while in the west the closest shores are the Greek islands of Karpathos and Rhodes at 380 km (Delipetrou et al. 2008). It has an extreme Mediterranean climate, with an average rainfall of 480 mm per year that places it among the top 20 water-deprived countries worldwide (Myers and Haines 2000).

The horizon scanning process involved three stages:

1. Determination of composition and scope of thematic groups
2. Preliminary consultation between experts within four thematic groups (plants, freshwater animals, terrestrial animals, and marine species), excluding microorganisms.
3. Consensus-building across the thematic groups

Composition and scope of the thematic groups

Experts for the thematic groups were invited based on their breadth of taxonomic and invasion ecology knowledge. Some of the experts had previous experience in horizon scanning. Many of the participants had specific expertise in the Mediterranean environment within both Cyprus but also neighbouring countries. The experts were allocated to the thematic groups based on their expertise which overall provided comprehensive coverage of taxa and environments (terrestrial, freshwater and marine). The scope of each thematic group was clearly defined and conveyed to all participants. Participants were instructed to include a species if they had any doubt regarding its allocation; brackish species, for example, were considered by more than one group, with information pooled during the plenary sessions.

Each of the four groups had at least two co-leaders (scientists with relevant ecological and invasion

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biology expertise) from Cyprus or the eastern Mediterranean and one international expert. Additionally, there were between six to eleven additional group participants selected by the group leaders on the basis of their experience in the field of IAS. Twenty-four participants from across Cyprus and 27 from the rest of Europe participated in this exercise from a variety of backgrounds: academia, private consultancies, government and the military.

Pre-workshop research and preparation

Each of the four thematic groups was given the task of collating a list of alien species that were considered likely to arrive within the next decade, to establish and have an impact on native biodiversity, ecosystems and/or human health. Lists generated from a previous EU horizon scanning exercise (Roy et al. 2014a, 2015) were circulated to all groups. The groups were instructed to assess these lists for relevance to Cyprus, removing and adding species as appropriate. The thematic groups did not compile a comprehensive list of all the sources consulted but derived information from various sources including peer-reviewed papers or inventories (Georgiades 1994; Hadjikyriakou and Hadjisterkotis 2002; Katsanevakis et al. 2009; Arianoutsou et al. 2010), online information, and expert opinion. Over a 6-week period the thematic groups completed this preliminary exercise by communicating through email, telephone and video-conferencing. In addition to compiling the lists, the thematic groups populated a spreadsheet template (Supplementary information 1), which included agreed scores on likelihood of arrival, establishment, spread and impact on biodiversity, ecosystems, and human health within each thematic group in advance of the workshop.

The spreadsheet template included the following headings for gathering information on a species' basic biology: taxon, common name(s), taxonomic group, functional group, native distribution, presence in the EU and thematic group. Likelihood of arrival, likelihood of establishment, and likelihood of impact on biodiversity were all scored on a scale of 1 (very unlikely) to 5 (very likely). As with Roy et al. (2014a), the overall score for each species was determined as the product of the scores for likelihood of arrival, establishment and impact on biodiversity (maximum score = 125), and the confidence in the overall score was expressed as low, medium or high. For scoring of confidence: Low (L) = no direct observational evidence is available or evidence is difficult to interpret or considered low quality; Medium (M) = some direct observational evidence is available but may be ambiguous or difficult to scale within the specific geographic context; High (H) = direct observational evidence is available and straightforward to interpret without controversy and considered high quality. Impacts on biodiversity were assessed by considering the following four parameters and their sub-categories (Branquart 2009; Vanderhoeven et al. 2015): dispersal potential (indicating potential to spread); colonisation of high conservation-value habitats; adverse impacts on native species (predation/herbivory, competition, transmission of pathogens and parasites to native species, genetic effects); and alteration of ecosystem functions (modification to nutrient cycling, physical modifications to the habitat, modifications of natural successions, disruption of food webs). Human health impacts were classified using the following categories: no impact, nuisance (including psychological effects), disease transmission, parasitism and poisoning/toxicity/allergy and other impacts such as IAS facilitating negative impacts on human health by other species (Table 1). A species could be attributed multiple human health impacts. Additional information, specifically within the context of Cyprus, was compiled on the likely pathways of arrival, types of biodiversity impact, impact mechanisms on other species, impact mechanisms on ecosystem function, impact on human well-being, socio-economic impacts, additional comments and references. The participants were given guidance notes on completing the spreadsheet (Supplementary Information 2).

Consensus building across thematic groups

Consensus building across the thematic groups took place at a workshop held at the Akrotiri Environmental Education and Information Centre in the Akrotiri Sovereign Base Area, Cyprus on the 28th April 2017. Each thematic group provided an overview of their high-ranking species. The thematic groups were then given the opportunity to revise scores and ranks following the overviews of the other thematic groups in order to moderate approaches to scoring across groups. The thematic groups subsequently re-convened, and, through discussions, consensus was

Table 1 Definitions of the human health impact categories used in this study with an illustrative example

Human health impact	Definition	Example
1. No impact on human health	No known adverse effects on human health	The Northern Brown Shrimp *Penaeus aztecus*
2. Nuisance	Inflicting negative effects on human well-being including psychological	Noise by frogs and toads, fear of snakes even if harmless
3. Disease transmission e.g. mosquito vectors	Vectoring pathogens that can cause diseases	Yellow fever, Zika virus, dengue, chikungunya, transmitted by mosquito vectors *Aedes aegypti* and *Aedes albopictus*
4. Poisoning, toxicity, allergy, injury	Humans exposed to IAS may experience direct negative effects through bites, stings, allergens, harm, affliction	Alien plants with allergenic pollen Invasive Hymenoptera such as the Asian Hornet *Vespa velutina*, Lionfish *Pterois miles*, catfish *Plotosus lineatus*
5. Others e.g. interactions with other IAS	IAS facilitating negative impacts	Indian house crow *Corvus splendens* as a host species, and mosquitoes which have a role in transmission of West Nile Virus (WNV)

achieved on the ranking of the top 100 species across all thematic groups.

After the workshop, the thematic groups were given the opportunity to review the list and specifically check the establishment status of the species and provide additional supporting information, including evidence of impacts and known or likely pathways; this final dataset is the one presented and analysed here. The likely pathways of arrival for each IAS were documented using the Convention of Biological Diversity terminology (CBD 2014; Harrower et al. 2018); Supplementary Information 3 lists these category definitions. The human health impacts for all taxa were also reviewed post-workshop by one of the authors (AFM). This ensured that human health impacts were comprehensively assigned based on available evidence including peer-reviewed sources but also grey literature where knowledge gaps exist.

Results

Two-hundred and twenty-five species across all thematic groups were combined into a long list for consideration during the workshop (Supplementary Information 3); the plant thematic group compiled additional information on impacts after the consensus workshop (Supplementary Information 4). The group reached consensus on the ranking of the top 100 species within the following bands: 1–20, 21–40, 41–100. All species ranked during the horizon scanning workshop were considered to be of relevance to the entire island of Cyprus, including the British SBAs. The top 20 species had the maximum score of 125 (Tables 2, 3) and are subsequently referred to as presenting 'very high' potential future risk to the island.

Among the top 20 species that received the highest score were two plants, ten terrestrial animals (two insects, three birds and five mammals), four marine species and four freshwater species (Tables 2, 3). We ranked a further 20 species as presenting a potential future high risk (species scoring 100), 64 as medium risk (species scoring 60–80) and 121 as low risk species (species scoring less than 60). This information is detailed in Supplementary Information 3.

A high proportion of the species predicted to impact biodiversity were also considered likely to impact on human health (Fig. 1). Sixty percent of the species with very high negative biodiversity impacts are known to be involved in the transmission of pathogens or diseases. Of the species that have high impacts on biodiversity, 40% of these are involved in disease transmission of some sort. Of these species, 20% are involved in a nuisance effect, such as noise for example, and 16% in direct negative health effects through poisoning, toxicity, allergies, bites or injuries (Fig. 1). The impact on human health was lower for IAS ranked as high, medium and low to biodiversity: 40%, 39% and 29% respectively.

Table 2 The 20 IAS agreed by experts within thematic groups (Plants, Terrestrial animals, Freshwater animals and Marine) as constituting the most likely to arrive (A), establish (B) and impact biodiversity and ecosystems (C)

Species	Taxon	Thematic group	Likelihood of arrival [A]	Likelihood of establishment [B]	Likelihood of impact on biodiversity [C]	A*B*C	Confidence
Acacia dealbata	Plant	Plants	5	5	5	125	H
Acridotheres tristis	Bird	Terrestrial animals	5	5	5	125	H
Amathia verticillata	Bryozoan	Marine	5	5	5	125	H
Channa argus	Fish	Freshwater animals	5	5	5	125	H
Chrysemys picta	Reptile	Freshwater animals	5	5	5	125	H
Codium parvulum	Seaweed	Marine	5	5	5	125	H
Linepithema humile	Insect	Terrestrial animals	5	5	5	125	H
Penaeus aztecus	Shrimp	Marine	5	5	5	125	H
Plotosus lineatus	Fish	Marine	5	5	5	125	H
Psittacula krameri	Bird	Terrestrial animals	5	5	5	125	H
Rattus norvegicus	Mammal	Terrestrial animals	5	5	5	125	H
Vespa velutina	Insect	Terrestrial animals	5	5	5	125	H
Arctotheca calendula	Plant	Plants	5	5	5	125	M
Corvus splendens	Bird	Terrestrial animals	5	5	5	125	M
Gambusia affinis	Fish	Freshwater animals	5	5	5	125	M
Mustela nivalis	Mammal	Terrestrial animals	5	5	5	125	M
Procambarus fallax	Crayfish	Freshwater animals	5	5	5	125	M
Procyon lotor	Mammal	Terrestrial animals	5	5	5	125	M
Sciurus anomalus	Mammal	Terrestrial animals	5	5	5	125	M
Sciurus vulgaris	Mammal	Terrestrial animals	5	5	5	125	M

Scores ranged from 1–5 and the product of A × B × C was used to provide a combined score and preliminary ranking of the IAS for discussion by all experts at the workshop who ultimately agreed the final list by consensus. Confidence levels (H = High, M = Medium, L = Low) were assigned to the combined score by the experts. Species are listed alphabetically within confidence groupings

Table 3 The 20 IAS agreed by experts within thematic groups (Plants, Terrestrial animals, Freshwater animals and Marine) as constituting the most likely to arrive, establish and impact biodiversity and ecosystems alongside the impact mechanisms for biodiversity, ecosystem function and human health (where human health impacts were identified)

				Impact mechanisms on biodiversity									Impact mechanisms on ecosystem function				Impact mechanisms on human health				
Latin name	Common name	Thematic Group	Confidence	1. Competition	2. Predation	3. Hybridization	4. Disease transmission	5. Parasitism	6. Poisoning / toxicity	7. Bio-fouling	8. Grazing / herbivory / browsing	9. Interactions with other IAS	1. Nutrient cycling	2. Physical modification of the habitat	3. Natural succession	4. Disruption to food webs	1. No impact on human health	2. Nuisance (e.g. noise)	3. Disease transmission (e.g. mosquito vectors)	4. Poisoning / toxicity / allergy / bite / injury	5. Others e.g. Interactions with other IAS
Acacia dealbata	Silver wattle, Blue wattle or Mimosa	Plants	H	X					X			X	X	X	X	X	X				
Acridotheres tristis	Common myna	Terrestrial animals	H	X	X											X		X	X		
Amathia verticillata	Spaghetti bryozoan	Marine	H	X						X			X	X	X	X	X				
Channa argus	Northern snakehead	Freshwater animals	H	X	X		X									X			X		
Chrysemys picta	Easter painted turtle	Freshwater animals	H																X		
Codium parvulum	A green alga	Marine	H	X						X		X	X				X				
Linepithema humile	Argentine ant	Terrestrial animals	H															X			
Penaeus aztecus	Northern brown shrimp	Marine	H	X								X			X		X				
Plotosus lineatus	Striped eel catfish	Marine	H	X	X				X			X	X			X		X		X	
Psittacula krameri	Ring necked parakeet	Terrestrial animals	H	X			X											X			
Rattus norvegicus	Brown rat	Terrestrial animals	H																X		
Vespa velutina	Asian hornet	Terrestrial animals	H		X													X		X	
Arctotheca calendula	Cape marigold, plain treasure-flower, capeweed	Plants	M	X					X			X		X	X	X				X	
Corvus splendens	Indian house crow	Terrestrial animals	M															X	X		X

Table 3 continued

				Impact mechanisms on biodiversity									Impact mechanisms on ecosystem function				Impact mechanisms on human health				
Latin name	Common name	Thematic Group	Confidence	1. Competition	2. Predation	3. Hybridization	4. Disease transmission	5. Parasitism	6. Poisoning / toxicity	7. Bio-fouling	8. Grazing / herbivory / browsing	9. Interactions with other IAS	1. Nutrient cycling	2. Physical modification of the habitat	3. Natural succession	4. Disruption to food webs	1. No impact on human health	2. Nuisance (e.g. noise)	3. Disease transmission (e.g. mosquito vectors)	4. Poisoning / toxicity / allergy / bite / injury	5. Others e.g. Interactions with other IAS
Gambusia affinis	Western mosquitofish	Freshwater animals	M	X	X						X	X	X			X	X				
Mustela nivalis	Weasel	Terrestrial animals	M														X				
Procambarus virginalis	Marbled crayfish	Freshwater animals	M		X						X	X	X	X		X	X				
Procyon lotor	Raccoon	Terrestrial animals	M																X		
Sciurus anomalus	Persian squirrel	Terrestrial animals	M																X		
Sciurus vulgaris	Red squirrel	Terrestrial animals	M														X				

Species are listed alphabetically within confidence groupings

Arrival pathways

Thirty-eight different arrival pathways at the Convention on Biological Diversity (CBD) subcategory level (see Supplementary Information 2 for full list) were assigned across the species listed (Supplementary Information 3). Freshwater animals had the highest overall number of pathways (12) attributed to their likely arrival, with plants and marine macrophytes, terrestrial animals species having the lowest number of arrival pathways (4) (Fig. 2). Even though freshwater animals had the highest number of pathways associated with their predicted arrival, it was more common for only one pathway type to be attributed to a freshwater animal species than multiple pathways, although across all groups 104 species had two or more likely pathways through which they could arrive.

Terrestrial animals, categorised as likely to have a very high or high impact on biodiversity, were considered likely to arrive through up to four pathways with a high proportion arriving by either one or two different pathways, such as the pet trade or escapes from zoos (Fig. 2). Plants are most likely to arrive through one or two pathways (with horticulture and forestry dominating) (Fig. 2). Similarly, only one or two pathways, particularly hull fouling and ballast water, are considered relevant for the majority of marine species, particularly those predicted to have the highest threat to biodiversity (Fig. 2). At the CBD level I category, escape was the dominant pathway across all biodiversity impact categories (Fig. 3). The pathways stowaway and corridor were the second most common pathways but these tended to be associated with species predicted to have low impact.

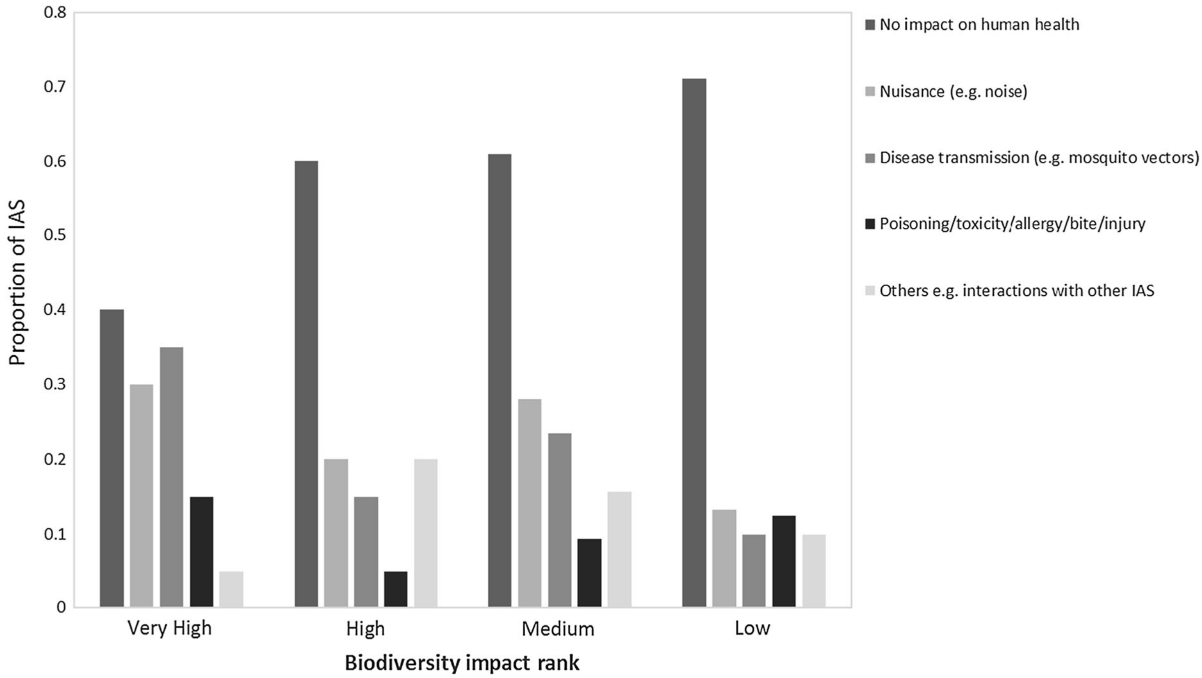


Fig. 1 Proportion of IAS ranked as very high, high, medium or low threat to biodiversity and ecosystems that either have no impact on human health or pose a threat to human health through nuisance, disease transmission, poisoning/toxicity/allergy/bite/injury or other human health impact

Pathways relating to food, botanical gardens, zoological parks and aquaria, horticulture and the pet trade are the main routes for species considered to have high impact on biodiversity (Fig. 4). Terrestrial animals and plants are predicted to be more likely to escape from captivity than marine species and freshwater animals (Fig. 5). Considering the escape pathway in more detail highlights that species kept as pets or in zoos and gardens are the most likely sources of escape for plants and terrestrial animals (Fig. 5). In contrast, pathways associated with ship movements (hull and ballast water contaminants) and natural dispersal through spread of IAS from existing invaded regions are anticipated to be the most likely sources of invasion for the marine environment, whereas food, pet, shipping, angling and aquaculture are the most likely for freshwater species (Fig. 5).

Discussion

It is widely accepted that IAS affect not only biodiversity and ecosystems but also socio-economic factors (Shine et al. 2010). However, assessment of the risks of IAS most often focus only on biodiversity, and sometimes also ecosystem function but there is a need for interdisciplinary approaches that embrace the concept of ecosystem services including human well-being (Vilà and Hulme 2017). In an attempt to address this need we developed a horizon scanning approach that considered the potential threat posed by IAS, predicted to arrive and establish on Cyprus, to biodiversity and ecosystems alongside human health. The vast array of information collated by the experts for many species highlights the complexity of the task. However, sufficient commonalities were apparent to enable experts from different disciplines to agree a prioritised list of IAS that were relevant at the scale of the entire island but also the SBAs, which have different governance. Following a method that included simple and transparent scoring criteria enabled experts from disparate disciplines to consider both human health, biodiversity and ecosystem impacts. Such an interdisciplinary approach should provide decision-makers with the necessary evidence to prioritise species for risk assessment (Roy et al. 2018a, b), ultimately leading to the development and implementation of pathway and management plans at

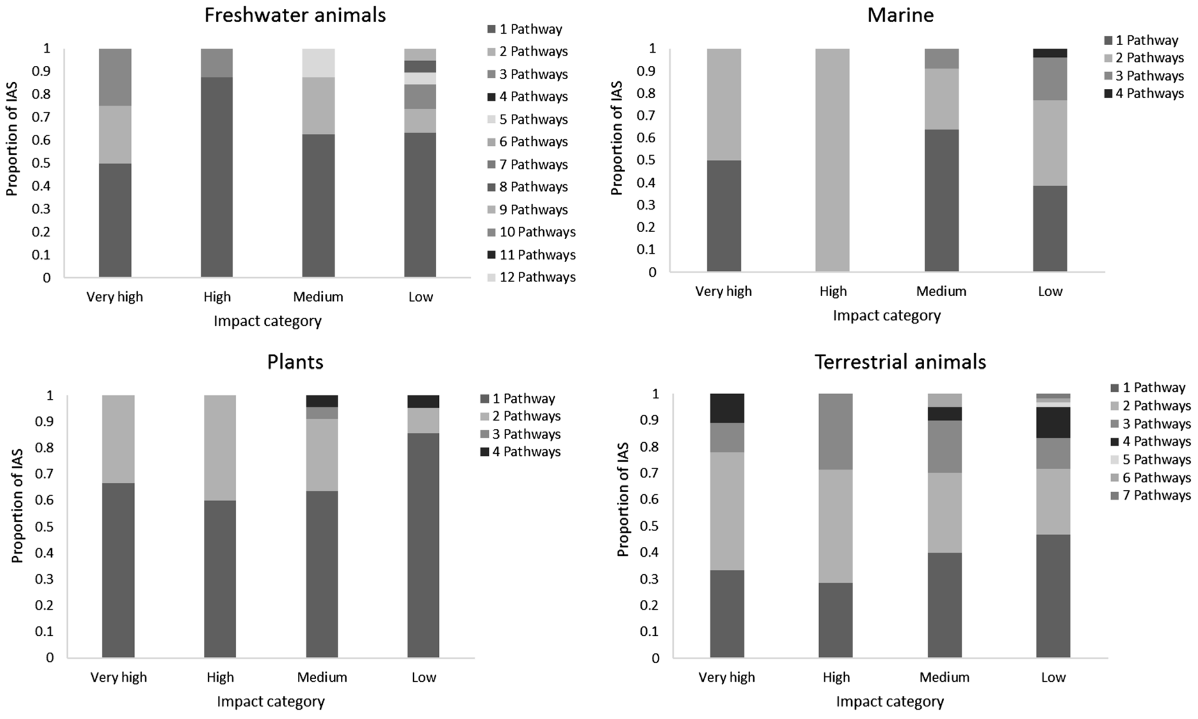
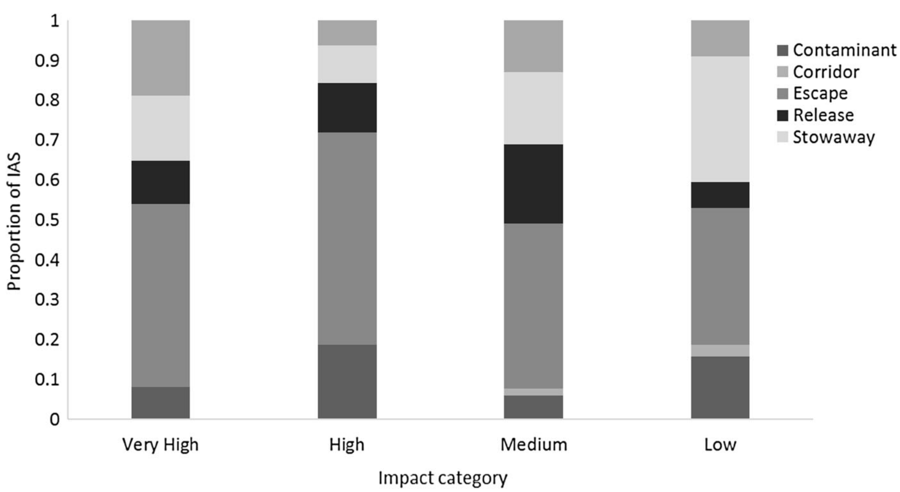


Fig. 2 Proportion of IAS within the four thematic groups (Freshwater animals, Marine, Plants, Terrestrial animals) ranked as very high, high, medium or low threat to biodiversity and ecosystems that are predicted to arrive through either one or multiple pathways of introduction (up to four for IAS identified through the Marine and Plants thematic groups or up to seven and 12 for Terrestrial animals and Freshwater animals respectively)

Fig. 3 Proportion of IAS ranked as very high, high, medium or low threat to biodiversity and ecosystems predicted to arrive through the CBD level I pathways of introduction: Contaminant, Corridor, Escape, Release, Stowaway or Unaided



various spatial scales, including the UK Sovereign Base Areas (SBAs) of Akrotiri and Dhekelia through to the wider island of Cyprus.

The IAS identified through our horizon scanning exercise spanned terrestrial, freshwater and marine environments; terrestrial IAS dominate the list and constitute over half of the species within the top 100. While freshwater habitats on Cyprus are limited and only 26 freshwater IAS were identified as a threat, it is important to note these that freshwater environments are particularly sensitive to invasion (Havel et al. 2015; Tricarico et al. 2016) and harbour important

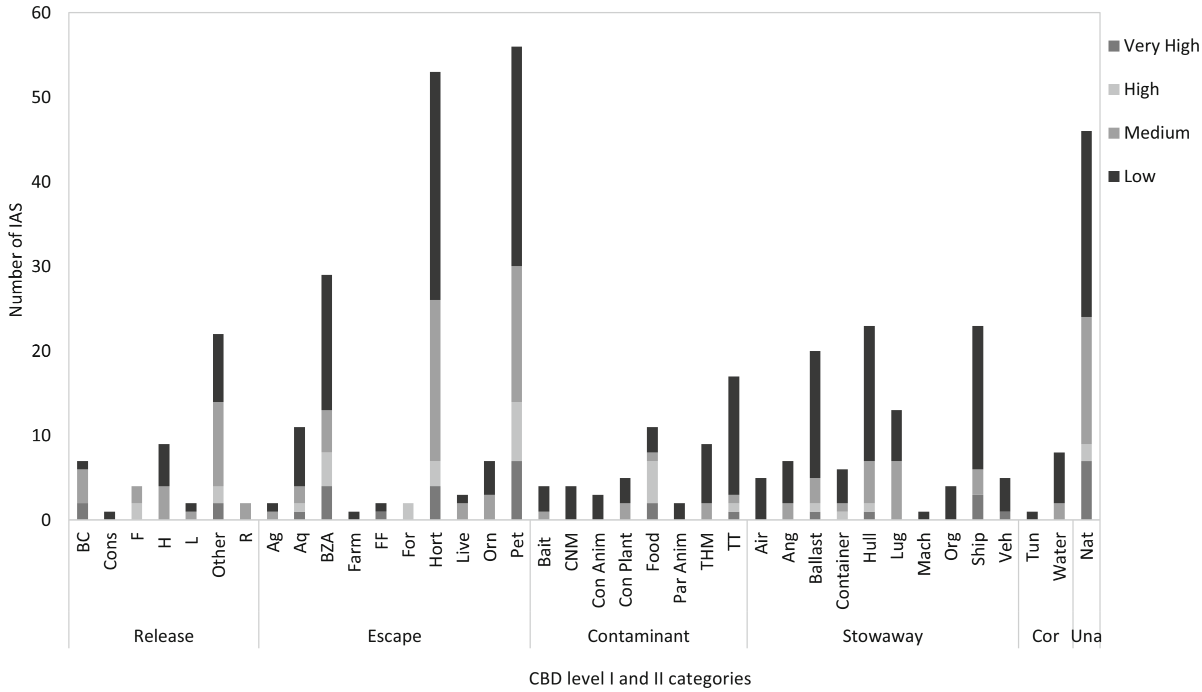


Fig. 4 Number of IAS ranked as very high, high, medium or low threat to biodiversity and ecosystems predicted to arrive through the CBD level II pathways of introduction and represented within their overarching CBD I category: Release: BC = Biological control; Cons = Introduction for conservation purposes or wildlife management; F = Fishery in the wild; H = Hunting; L = Landscape/flora/fauna "improvement" in the wild; Other = Other escape from confinement; R = Research and ex situ breeding; Escape: Ag = Agriculture; Aq = Aquaculture/mariculture; BZA = Botanical garden/zoo/aquaria; Farm = Farmed animals; FF = Fur farms; For = Forestry; Hort = Horticulture; Live = Live food and live bait; Orn = Ornamental purpose other than horticulture; Pet = Pet/aquarium/terrarium species; Contaminant: Bait = Contaminated bait; CNM = Contaminant nursery material; Con Anim = Contaminant on animals; Con Plant = Contaminant on plants; Food = Food contaminant; Par Anim = Parasites on animals; THM = Transportation of habitat material; TT = Timber trade; Stowaway: Air = Hitchhikers in or on airplane; Ang = Angling/fishing equipment; Ballast = Ship/boat ballast water; Container = Container/bulk; Hull = Ship/boat hull fouling; Lug = People and their luggage/equipment; Mach = Machinery/equipment; Org = Organic packing material, in particular wood packaging; Ship = Hitchhikers on ship/boat; Veh = Vehicles; Corridor (Cor): Tun = Tunnels and land bridges; Water = Interconnected waterways/basins/seas); Unaided (Una): Nat = Natural dispersal across borders of invasive alien species that have been introduced through pathways 1–5

biodiversity (Gucel et al. 2012). Furthermore, there are a number of factors, in addition to IAS, that are adversely affecting freshwater biodiversity including aquaculture, water extraction and climate change. Within the marine environment 16 IAS were considered to pose a potential threat. There has been an increase in the arrival of marine IAS to the Mediterranean following the opening and periodic widening of the Suez Canal. These so-called Lessepsian migrant species are arriving from the Red Sea into the Levantine Basin (eastern Mediterranean) where Cyprus is situated. However, fouling of ships, ballast water exchange, aquaculture, and the aquarium trade are also responsible for the introduction of IAS into this region (Streftaris and Zenetos 2009). In 2008, it was estimated that the number of recorded alien species in the Mediterranean Sea was continuing to increase at a rate of one new record every 9 days (Zenetos et al. 2008; Katsanevakis et al. 2009). Latest reports (2010–2016), considering only multicellular alien species, indicate the rate of introductions is 11 species per year (Zenetos et al. 2017). The Mediterranean Sea, including Cyprus, can be considered an early-warning system for other European marine environments; it has been estimated that 76% of the first marine introductions of IAS across Europe were reported first from the Mediterranean Sea, with 54% first reported in the eastern Aegean-Levantine Sea

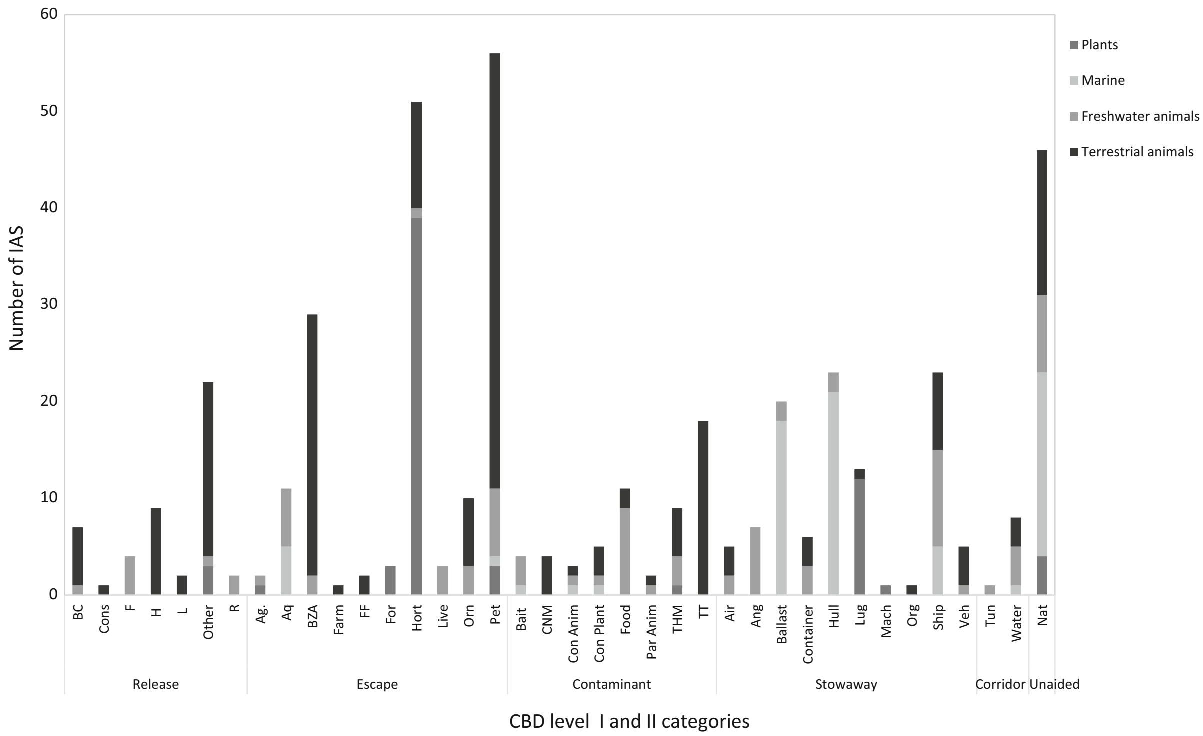


Fig. 5 Number of IAS across the four thematic groups (Plants, Marine, Freshwater animals and Terrestrial animals) ranked as very high, high or medium impact on biodiversity and ecosystems within the CBD subcategory pathways, and represented within their overarching CBD I category: Release: BC = Biological control; Cons = Introduction for conservation purposes or wildlife management; F = Fishery in the wild; H = Hunting; L = Landscape/flora/fauna "improvement" in the wild; Other = Other escape from confinement; R = Research and ex situ breeding; Escape: Ag = Agriculture; Aq = Aquaculture/mariculture; BZA = Botanical garden/zoo/aquaria; Farm = Farmed animals; FF = Fur farms; For = Forestry; Hort = Horticulture; Live = Live food and live bait; Orn = Ornamental purpose other than horticulture; Pet = Pet/aquarium/terrarium species; Contaminant: Bait = Contaminated bait; CNM = Contaminant nursery material; Con Anim = Contaminant on animals; Con Plant = Contaminant on plants; Food = Food contaminant; Par Anim = Parasites on animals; THM = Transportation of habitat material; TT = Timber trade; Stowaway: Air = Hitchhikers in or on airplane; Ang = Angling/fishing equipment; Ballast = Ship/boat ballast water; Container = Container/bulk; Hull = Ship/boat hull fouling; Lug = People and their luggage/equipment; Mach = Machinery/equipment; Org = Organic packing material, in particular wood packaging; Ship = Hitchhikers on ship/boat; Veh = Vehicles; Corridor (Cor): Tun = Tunnels and land bridges; Water = Interconnected waterways/basins/seas); Unaided (Una): Nat = Natural dispersal across borders of invasive alien species that have been introduced through pathways 1–5

(Tsiamis et al. 2018). Management of marine invasions is known to be exceptionally difficult (Russell et al. 2017) and the feasibility of eradicating marine species is particularly low (Booy et al. 2017), preventing their arrival is therefore critical.

Invasive alien birds, ants, rodents and other mammals constitute some of the greatest threats to biodiversity (Jeschke 2008; Ward et al. 2008), and these are well-represented within our list. Many of these animals have serious impacts on biological diversity and/or human activities, such as common myna *Acridotheres tristis*, Argentine ant *Linepithema humile* and Italian wall lizard *Podarcis sicula*. The Italian wall lizard is native to the Italian Peninsula and Sicily but arrived as a hitchhiker on cargo and through the nursery trade on several Mediterranean islands, with similarities to Cyprus, and subsequently established (Silva-Rocha et al. 2014) with documented impacts through competitive exclusion of and hybridisation with native lizards (Nevo et al. 1972; Capula et al. 2002; Downes and Bauwens 2002). The common kingsnake *Lampropeltis getula*, commonly kept as a pet, established on the Macaronesian islands in the North Atlantic Ocean (Monzón-Argüello et al. 2015).

This generalist predator could establish on Cyprus and have major adverse effects on native species (including other snakes, turtles, small mammals and birds) (Roy et al. 2018a). Several studies have shown that introduced snakes can have devastating impacts on native (often endemic) herpetofauna of Mediterranean islands, and so impact upon the natural and cultural heritage of island ecosystems, whose inhabitants often consider native species as iconic (Cabrera-Pérez et al. 2012; Silva-Rocha et al. 2018).

Eight of the 20 species predicted to present a very high impact on biodiversity and ecosystems were also considered a threat to human health. It is widely recognised that little is known about the biology of alien pathogens, disease-causing parasites including viruses, bacteria, fungi, protists, and nematodes, and their impacts on after introduction into new regions (Roy et al. 2017). However, we have demonstrated the value of coupling expert opinion with the best available evidence to apply a broad classification of human health impacts within horizon scanning. Here we provide a few examples that demonstrate the value of such an approach in at least making preliminary predictions and highlighting priorities for future research.

Acacia dealbata is an invasive tree species which prefers disturbed habitats, but is also found invading undisturbed plant communities globally (Lazzaro et al. 2014). It reduces biodiversity by competing with native plants, replacing grass communities and increasing water loss from riparian habitats (Lorenzo et al. 2010). *Acacia dealbata* can also have direct effects on human health through the production of allergenic pollen (Lorenzoni-Chiesura et al. 2000). Furthermore, it has been shown that the increased availability of sugar sources provided by some *Acacia* species can increase the longevity of female *Anopheles sergentii* and so enhance their potential to vector malaria (Gu et al. 2011). It has been suggested that local shortages of sugar resources might impede completion of the mosquitos' gonotrophic cycle and reduce vector capacity (Gu et al. 2011). Malarial transmission is increased 250-fold when additional sugars are available such as from *Acacia* nectar (Gu et al. 2011). Therefore, interactions between mosquitoes and invasive *Acacia* could increase human health risks. A number of species of invasive mosquitoes were considered through our study and, although their impacts on biodiversity are likely to be negligible, the threat they pose to human health is of considerable concern (Martinou and Roy 2018). Therefore, there could be merit in studying whether the establishment of *A. dealbata* could facilitate the transmission of malaria by providing sugar resources for vector-competent mosquito species already present in Cyprus.

Within the marine environment one of the IAS that has impacts upon biodiversity and human health is the striped eel catfish, *Plotosus lineatus* (Galil 2018). This species has venom glands in its dorsal and pectoral spines and in glandular cells in its skin that secrete a potent toxin (Galil et al. 2017; Galanidi et al. 2018). The injuries it can inflict, particularly on fisheries personnel, can be severe (Gweta et al. 2008). The striped eel catfish is also considered as one of the 100 worst IAS in the Mediterranean on account of both its ecological and human health impacts (Streftaris and Zenetos 2006; Galil 2018).

A number of the IAS predicted to threaten biodiversity and ecosystems are also anticipated to have multiple human health impacts. The Indian house crow *Corvus splendens* has an obligate association with people and no populations are known to exist independently from humans (Nyári et al. 2006). Invaded areas are mainly urban and semi-urban where the house crows benefit from human food and refuse, although they often nest and roost within nearby farmland and have been shown to reduce bird diversity (Ryall 1992). House crows affect human health as reservoirs of diarrheal diseases and West Nile Virus (Komar et al. 2003) but are also a nuisance to humans. It is intuitive to consider IAS that exert multiple human health impacts as having an increased threat but we did not attempt to rank the categories of human health impact. However, disease vectors such as mosquitoes should perhaps be of greater concern than an IAS considered to cause nuisance such as noise but further work is required to develop approaches for comparing and scoring such human health impacts. The magnitude of health impacts (e.g. prevalence, incidence, morbidity) could be further investigated using specific impact assessment protocols (D'hondt et al. 2015). Also, there is potential to integrate the recently published Socio-Economic Impact Classification for Alien Taxa (SEICAT) (Bacher et al. 2017) within an horizon scanning framework.

The underlying importance of arrival pathways in the invasion process has been well documented (Essl et al. 2015). Management of pathways may provide an effective method for preventing the arrival of IAS (McGeoch et al. 2016). The importance of identification, prioritization and management of introduction pathways has also been recognized at policy level as both the CBD and the EU, through the EC Biodiversity Strategy to 2020 and the IAS Regulation, have dedicated targets for combating IAS through management of pathways (Shine et al. 2010; CBD 2014). Therefore, in this study we documented the likely pathways of arrival for the IAS, identified as a potential threat to Cyprus through our horizon scanning approach, using the CBD hierarchical classification system (CBD 2014). It is important to note that the probability of arrival and pathways assigned were within the context of Cyprus including the SBA. Perhaps most notable is the number of pathways that are relevant across all the identified IAS; multiple pathways of arrival are anticipated for many IAS. This presents a challenge with respect to pathway management but it is encouraging that pathways within the escape category dominate, and biosecurity measures could be effective here. However, stowaway is also recognised as a major pathway of arrival; this was also apparent from the GB horizon scanning exercise (Roy et al. 2014a). There are ways to manage and reduce stowaways; through, for example, dedicated biosecurity checks at entry points but naturally, the covert nature of IAS arriving as stowaways presents challenges. Currently, the Republic of Cyprus has established procedures at entry points to ensure official control is in place for intentional introductions of IAS of EU concern and for species that fall under the plant health and animal health legislations. The identification and prioritization of unintentional pathways of IAS from both outside and within the EU, as well as pathways related to non-commercial introductions, are important steps towards the implementation of additional checks and relevant biosecurity measures.

Putting measures in place to tackle introduction pathways requires detailed knowledge of the exact goods and commodities associated with species introductions, for example from interception databases, as well as dedicated surveillance methods. However, the legislative frameworks and agreements in which trade exists should also be taken into account. A lack of interception databases presents a particular challenge to horizon scanning (and also risk assessment and subsequent management). Although logistically difficult to compile, and recognising the need to adhere to recent data privacy requirements embodied within the General Data Protection Regulation, such databases could provide a robust evidence-base for future forecasting through horizon scanning but also underpin evaluation and inform subsequent IAS management. In the absence of data on pathways, such as frequency of species imports, lists and numbers of species kept in captivity and/or sold through the pet trade, there is considerable reliance on the knowledge of experts, particularly ecologists, to predict the movement (and establishment) of potential IAS into new regions. The absence of robust data impairs the ability to apply modelling approaches identifying emerging invasion pathways for stowaway species that are unintentionally transported via goods and services (Tingley et al. 2017).

An interdisciplinary approach to horizon scanning processes, such as the one we have reported here, requires a breadth of expertise from medical and environmental health through to ecology, but the benefits of a collaborative approach are far-reaching. Preliminary lists can be effectively and rapidly agreed by bringing together small interdisciplinary teams and using the methods described here. However, gaps in expertise are inevitably identified through the discussions. It is important to document and assign appropriate confidence levels on the basis of these gaps and to recognise that horizon scanning lists are the first stage in prioritisation of IAS to inform decision-making (Roy et al. 2015, 2018a, b). The information gathered through such rapid screening is by necessity less comprehensive than could be achieved through risk assessment (Roy et al. 2018a, b), but horizon scanning provides a short list of species that can be prioritised for full risk assessment. This should be the next step. Additionally, the list can be used to rapidly inform surveillance, monitoring and can guide biosecurity efforts. For example, there are a number of species that could be included within citizen science initiatives with the purpose of both awareness raising and early-warning (Zenetos et al. 2013; Galil et al. 2018). Although it is important to note the difficulties inherent in using citizen science approaches, particularly for early-warning of IAS with low detectability (Pocock et al. 2017), it is encouraging to note a number of successes within the Mediterranean region. In Greece, 28 records were received from the public for marine alien species including the invasive pufferfish, *Lagocephalus sceleratus* (Zenetos et al. 2013). The mapping of the distribution of the lionfish *Pterois miles* in Cyprus can be partially attributed to citizen scientists (Jimenez et al. 2016; Kletou et al. 2016). In Israel the annual swarming of the venomous jellyfish *Rhopilema nomadica* has been monitored since the 1990s by a network of swimmers, surfers, lifeguards, yachters, fishermen and others leading to the development of the Mediterranean-wide "JellyWatch" programme (http://www.ciesm.org/marine/programs/jellywatch.htm) (Galil et al. 2018). Additionally, voluntary sharing through social media of IAS sightings by recreational fishermen has not only provided an up-to-date information on the distribution of channel catfish (*Ictalurus punctatus*) and European catfish (*Silurus glanis*) within the invaded range, but also contributed to understanding of the temporal and spatial spread in two Iberian watersheds (Gago et al. 2016; Banha et al. 2017).

It is clear that coordinated and interdisciplinary approaches are key to understanding, detecting and managing the emergence of IAS and their impacts on people and biodiversity at various scales. Robust risk assessments (Roy et al. 2018a, b) are critical for underpinning strategic and legislative decision-making but horizon scanning provides a way to prioritise IAS for this next step, which usually involves a considerable investment of resources. Furthermore, the identification and prioritisation of IAS can be engaging for people and provide a focus for citizen science approaches to monitoring IAS. People are an intimate part of invasion ecology, their actions result in the introduction of IAS, and it is critical that they are part of the solution to reduce the future threat of IAS.

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