Horizon scanning to predict and prioritise invasive alien species with the potential to threaten human health and economies on Cyprus

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Abstract

Invasive Alien Species (IAS) are known to be a major threat to biodiversity and ecosystem function and there is increasing evidence of their impacts on human health and economies globally. We undertook horizon scanning using expert-elicitation, to predict arrivals of IAS that could have adverse human health or economic impacts on the island of Cyprus. Three hundred and twenty five IAS comprising 89 plants, 37 freshwater animals, 61 terrestrial invertebrates, 93 terrestrial vertebrates and 45 marine species, were assessed during a two-day workshop involving forty-two participants both present in person at the workshop and through email correspondence, to derive two ranked lists: 1. IAS with potential human health impacts (20 species) and 2. IAS with potential economic impacts (50 species ranked in bands of 1-10, 11-20, 21-50). Five species of mosquitoes (*Aedes aegypti*, *Aedes albopictus*, *Aedes flavopictus*, *Aedes japonicus* and *Culex quinquefasciatus*) were considered a potential threat to both human health and economies. It was evident that the IAS identified through this process could potentially arrive through many pathways (25 and 23 pathways were noted for the top 20 IAS on the human health and economic impact lists respectively). *Contaminant on plants*, *pet / aquarium / terrarium species (including live food for such species)*, *hitchhikers in or on aeroplanes*, *hitchhikers in or on ship / boats* and *vehicles* were the main pathways that arose across both lists. We discuss the relevance of horizon scanning lists to inform biosecurity policies and communication on IAS, highlighting the importance of increasing understanding amongst all stakeholders, including the public, to reduce the risks associated with IAS on the horizon.

Key words

Prevention; policy; negative impact, Mediterranean Sea, introduction pathways, communication.

Introduction

Invasive alien species (IAS), species introduced either intentionally or unintentionally by humans outside of their native range, and causing negative impacts to biodiversity, ecosystem services, economy and / or society, are a major concern globally (Russell et al. 2017, Pauchard et al. 2018, Díaz et al. 2019, Stoett et al. 2019). There is growing evidence of adverse effects of IAS on ecosystem function (Schindler et al. 2015, Vilà and Hulme 2017), ecosystem services (such as crop production, timber provision, seafood and recreation) and to economies and human health (Schindler et al. 2015, Martinou and Roy 2018).

IAS can have direct negative impacts on human health through disease transmission, for example certain mosquito species (Moore and Mitchell 1997) or through having highly allergenic pollen as is the case with some plants (Samson et al. 2017, Lazzaro et al. 2018). There are also examples of poisonous or venomous marine IAS causing direct health impacts, e.g. the venomous striped eel catfish *Plosotus lineatus* was responsible for 10 % of the marine organism related injuries experienced by fishermen off the coast of Israel (Gweta et al. 2008). Additionally, the presence of IAS can have indirect health impacts that might, for example, be caused by loss of agricultural production and food security or by causing traffic accidents (Schindler et al. 2015). Economically, costs of direct impacts and management of IAS to agriculture, forestry and fisheries were estimated at minimum €12.5 billion in Europe in 2012, but this was considered a conservative estimate (Kettunen et al. 2009). In Great Britain, the cost to the economy incurred by IAS was estimated at £1.7 billion in 2010 (Williams et al. 2010).

Predicting the arrival of IAS and prioritising their prevention are seen as critical for informing biosecurity and management of such species (Shine et al. 2010, Caffrey et al. 2014, Roy 2015, Booy et al. 2017) with the ultimate goal of reducing the risk and impacts of IAS. Such prioritised lists of potential IAS provide an important tool to guide monitoring to inform early-warning, preventative action through pathway action plans and biosecurity, as well as to communicate risk to all

stakeholders, including the public. Here, we present the outcomes of a horizon scanning study using an expert-elicitation approach, which has previously been used in Great Britain (Roy et al. 2014), Europe (Roy et al. 2019a) and the United Kingdom Overseas Territories (Roy et al. 2019b). We build on a previous study in which a priority list of IAS with the potential to threaten biodiversity and ecosystems was derived for Cyprus through expert elicitation (Peyton et al. 2019). IAS within this list which were also considered to pose a risk to human health were noted but not scored (Peyton et al. 2019). Here we extend this approach to predict marine, terrestrial and freshwater IAS which have the potential to pose a threat to human health and economies for the island of Cyprus, including the Sovereign Base Areas of Akrotiri and Dhekelia.

Methods

Study Area

Cyprus located in the eastern Mediterranean, is the third largest island in the Mediterranean and is bordered with Asia to the north and east, Europe to the west and Africa to the south. The Mediterranean basin is renowned for being a biodiversity hotspot (Myers et al. 2000) and Cyprus has a high level of endemism across different taxonomic groups (Sparrow and John 2016). Cyprus hosts a diverse range of habitats from winter snow-capped mountains, conifer forest (e.g. the endemic Cyprus cedar *Cedrus brevifolia*) and coastal cliffs to saltmarsh, riverine and agricultural plains. Potatoes, wine, citrus are among products exported from Cyprus.

Other members of the European Union are the most important trading partner of Cyprus, with goods imported primarily from Greece, UK, Italy and Germany (Ministry of Energy 2014). In addition to strong trade links across Europe, it is estimated that over €2.23 billion revenue was generated from tourism for the period of January to September 2019 (Statistical Service of the Republic of Cyprus 2019).

Expert elicitation workshop

145 The workshop (27-29 November 2019) considered human health and economic impacts for the
146 island of Cyprus, following the methods of Roy et al. (2019b). Experts were assigned to five broad
147 thematic groups: plants (terrestrial and freshwater), freshwater animals (invertebrates and fish),
148 terrestrial invertebrates, terrestrial vertebrates, and marine species (invertebrates, vertebrates and
149 primary producers). Mosquitoes were included within the freshwater group.

150 Experts were asked to score each potential IAS within their thematic group for their separate
151 likelihoods of: i) arrival, ii) establishment, iii) magnitude of the potential negative impact on human
152 health or economies. Quantification of the impact score on human health and economy were
153 performed using a scoring scheme modified from the SEICAT system (Bacher et al. (2018); Table 1).
154 Only primary impacts were considered, for example, should a person be off sick from work because
155 they were ill from a mosquito-borne infection, this would only be considered within human health
156 not economic impact. We used a 3-criterion, 5-point scoring system, by which a maximum score of
157 125 could be produced for any one IAS. For all the IAS included within the priority lists, we
158 documented the pathways using the CBD pathway classification system (CBD 2014, Harrower et al.
159 2018) by which they are most likely to arrive. The temporal scope for the predictions was of IAS
160 likely to arrive in the next ten years.

161 Experts performing the scoring had a range of experience within the disciplines of human health,
162 social economics and invasion biology (see supplementary material 1 for the full list of participants
163 involved in the scoring). The geographic scope of the search for potential IAS was global but with the
164 following restrictions, IAS were only considered:

165 (i) If currently absent from Cyprus. Farmed animals such as goats *Capra hircus* were considered
166 established in the wild and, therefore, the potential for feral invasive populations was not
167 considered here.

168 (ii) If there was sufficient documented invasion histories illustrating undesirable impacts in
169 other regions.

(iii) If pathways of introduction of the IAS are active, that is:

a. The IAS are traded within Cyprus or are present in areas that have strong trade or travel connections with Cyprus and there is a recognised potential pathway of introduction.

b. The IAS are present in captivity including in gardens, zoological parks, private collections, pet shops, aquaculture facilities or greenhouses.

Consultation on proposed IAS was undertaken between experts through e-mail discussions in advance of the workshop and through the workshop breakout groups. The long-list of IAS derived from the 2017 horizon scan for IAS to impact Cypriot biodiversity and ecosystem services of Peyton et al. (2019) was used as a starting point from which the thematic groups further updated, modified and developed the lists through consultation of relevant databases (e.g. CABI compendium and horizon scanning tool, GBIF, GRIIS, CyDAS) and other sources including peer-reviewed literature. Additionally, IAS of note from a recent study prioritising IAS for the UKOTs were also considered during this initial selection (Roy et al. 2019b). IAS that had arrived or been recorded in Cyprus subsequent to the 2017 scan were noted and removed from the long-list. In order to reduce potential bias that can occur with any expert-elicitation process (Sutherland and Burgman 2015), the process followed the ten guiding principles, outlined in (Roy et al. 2020).

Results

A total of 325 IAS were compiled into a long-list for consideration during the human health and economic impacts workshop. These 325 IAS consisted of 89 plants, 37 freshwater animals, 61 terrestrial invertebrates, 93 terrestrial vertebrates and 45 marine species. Two prioritised IAS lists were created.

The group reached a consensus on the ranking of the top 20 IAS predicted to have the potential for human health impacts in bands of 1-10 and 11-20 (Table 2) while the top 50 IAS predicted to have

195 the potential for economic impacts were ranked in bands of 1-10, 11-20, 21-50 (Table 3).
196 Supplementary information 2 gives the full list of 325 IAS reviewed during the workshop. Pathway
197 information where known, was collected for these species.

198 There were no terrestrial vertebrates listed within the human health top 20 list (**Error! Reference**
199 **source not found.**). Freshwater animals (mosquito IAS: yellow fever mosquito *Aedes aegypti*, Asian
200 tiger mosquito *Ae. albopictus*, *Ae. flavopictus*, Asian bush mosquito *Ae. japonicus* and southern
201 house mosquito *Culex quinquefasciatus*) comprised one quarter of the species in the human health
202 list. Plants, followed by marine IAS, were the second and third most numerous thematic groups after
203 freshwater animals.

204 Within the economic impact, the numbers within each thematic group were more evenly matched,
205 with plants and freshwater animals having the higher number of IAS listed within the top 20 but with
206 broadly similar numbers as terrestrial invertebrates and terrestrial vertebrates, with marine IAS
207 being least represented in the economic impact (**Error! Reference source not found.**). The IAS
208 ranked from 21-50 within the list of IAS constituting a potential threat to economies within Cyprus
209 included 13 invasive alien plant species, six marine IAS, five terrestrial invertebrates and terrestrial
210 vertebrates and a single freshwater animal (Table 3).

211 Of the IAS designated within the top 20 IAS constituting a potential threat to human health and
212 economies, ten were considered a potential threat to both human health and economies while the
213 remaining 20 were only included in one or other of the lists. Five species of mosquito (*Ae. aegypti*,
214 *Ae. albopictus*, *Ae. flavopictus*, *Ae. japonicus* and *C. quinquefasciatus*) were included with the list of
215 ten IAS appearing on both the human health and economic impact lists. Three plant IAS (ragweed
216 *Ambrosia artemisiifolia*, Cape ivy *Delairea odorata* and whitetop weed *Parthenium hysterophorus*)
217 and two marine IAS (white stinger *Macrorhynchia philippina* and *P. lineatus*) also spanned both
218 impact groups.

Twenty-five CBD Level II (subcategories) were identified for the top 20 IAS for human health and 23 pathways identified for the top 20 IAS for economy (Figure 2). *Contaminant on plants*, *pet / aquarium / terrarium species (including live food for such species)*, *hitchhikers in or on aeroplanes*, *hitchhikers in or on ship / boats and vehicles* were the main pathways that arose across both the list of IAS with potential human health and economic impacts.

For plants and freshwater animals, 14 separate arrival pathways were identified, for terrestrial animals seven were identified, five for terrestrial vertebrates and six for marine IAS (Figure 3). Marine, freshwater animals, terrestrial invertebrates and plants were considered more likely to be introduced via *Transport pathways*, both as contaminants or stowaways, whereas terrestrial vertebrates were considered more likely to be introduced through *Release* or *Escape* pathways. For marine IAS, *Corridor - interconnected waterways / basins / seas*, namely the Suez Canal, was noted as an important pathway.

Thirty-eight IAS were removed from the (Peyton et al. 2019) biodiversity and ecosystem short list of 225 IAS: four plants, four freshwater animals, eight terrestrial invertebrates, seven terrestrial vertebrates, thirteen marine animals and two marine plants. For the plants IAS that were removed, species were described for Cyprus subsequent to the 2017 workshop, although they may have arrived and established in Cyprus prior to 2017 e.g. fountain grass *Pennisetum setaceum* (Department of Environment 2019, Hand 2019) and small-leaf spiderwort *Tradescantia fluminensis* (Spitale and Papatheodoulou 2019).The four freshwater IAS (two mosquitofish fish (*Gambusia* spp.), Nile tilapia *Oreochromis niloticus*, and two crustaceans: Louisiana crayfish *Procambarus clarkii* (data from Department of Environment (2019), Martinou (2019), Ueda (2020), tadpole shrimp *Triops cancriformis*) (Tziortzis et al. 2014) were removed because they were already established in Cyprus. Terrestrial invertebrates were removed because they were previously overlooked or there was recently published evidence of their presence on Cyprus, e.g. three ants fire ant *Solenopsis geminata*, *Pheidole indica* and pharoah ant *Monomorium pharaonis* (Salata et al. 2017). Terrestrial vertebrates were either removed because they were established, e.g. brown rat *Rattus norvegicus*

(Psaroulaki et al. 2006) or not relevant because of the absence of active pathways, e.g. Canadian beaver *Castor canadensis* and American mink *Neovison vison*. Wild boar *Sus scrofa* was added to the list as there had been past (1990s) releases for hunting in Cyprus, but populations were subsequently eradicated (Hadjisterkotis and Heise-Pavlov 2006). The marine IAS list was considerably reduced as (a) three IAS were reported from the island since 2017 (killer algae *Caulerpa taxifolia* var *distichophyla*, the bryozoan *Amathia verticillata* and common moon crab *Matuta victor*); (b) one IAS (white crust tunicate *Didemnum perlucidum*) is cryptogenic (a species that cannot be reliably demonstrated as being either introduced or native (Carlton 1996)) and hence removed; and (c) for the remaining eleven IAS the likelihood of arrival (mainly through shipping) and establishment was re-evaluated as low, and hence removed.

Discussion

Prioritising IAS is an important component of IAS management, with clear ecological and economic benefits (Caffrey et al. 2014, Roy 2015, Booy et al. 2017). The lists of IAS predicted to arrive, establish and have adverse effects on human health and / or economies derived through this horizon scanning study, complement the list derived in 2017 for IAS predicted to impact biodiversity and ecosystems (Peyton et al. 2019). The 325 IAS identified span a diverse range of taxa, habitats and ecosystems.

The list of IAS predicted to have human health impacts was dominated by mosquitoes. Mosquitoes are considered to be the most important vectors of disease (Romi et al. 2018). The invasion of the Asian tiger mosquito *Ae. albopictus*, a competent vector of disease, in the Mediterranean is facilitated by climate change (Roiz et al. 2011) and has caused outbreaks of chikungunya fever in Italy (Rezza et al. 2007, Riccardo et al. 2019). France, Croatia and Spain have reported autochthonous (i.e. locally acquired) cases of dengue fever linked to established *Ae. albopictus* populations (Succo et al. 2016, ECDC 2019) and the risk of introduction of *Ae. albopictus* to Cyprus is

a major concern. In addition to the risk of disease transmission, mosquitoes can also be considered a nuisance and can affect human well-being. They can deter visitors from recreational spaces, which in turn causes adverse economic impacts (Medlock and Vaux 2015, Martinou et al. 2020). Recognising the paucity of knowledge on invasive diseases (Roy et al. 2017), we excluded pathogens and other disease causing agents other than those transmitted by invasive alien vectors, such as mosquitoes. However, it was noted that the ongoing spread of the plant pathogenic bacterium *Xylella fastidiosa* in the Mediterranean region was seen as of major concern and a threat for the economy. The bacterium causes serious diseases in a wide range of plants, including olive trees, and is transmitted by different Hemiptera species. Although it is an EPPO quarantine organism, and measures are in place, its arrival on Cyprus would potentially have significant detrimental economic impact, e.g. Saponari et al. (2019).

Although many vertebrates are known to be reservoirs and / or vectors of disease (Hulme 2014), irreversible impacts over large areas or large groups of people were considered unlikely to occur (Bacher et al. 2018). This paper was written during the COVID-19 pandemic. The authors acknowledge the severity and irreversible impact of zoonotic diseases but also note that critical knowledge gaps still exist in predicting the impacts of disease within invaded regions (Roy et al. 2017).

Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species (the 'IAS Regulation') requires Member States to identify and prioritise pathways of unintentional introduction and spread of IAS of Union concern. Ranked lists are also valuable for the development of action plans to tackle priority pathways of introduction and spread. Five IAS of Union concern occurred within the two top 20 lists: *Eichhornia crassipes; P. hysterophorus; P. lineatus; raccoon Procyon lotor* and *Vespa velutina*. The European and Mediterranean Plant Protection Organisation (EPPO) is an intergovernmental organisation for plant health that covers the European and Mediterranean region. There is one EPPO A1 species citrus longhorn beetle *Anoplophora glabripennis* (A1 species are absent from the EPPO region) and three

296 EPPO A2 species *Eichhornia crassipes*, grape phylloxera *Daktulosphaira vitifoliae*, and Colorado
297 potato beetle *Leptinotarsa decemlineata* (A2 species are locally present in the EPPO region) on our
298 list. Cyprus also has a protected zone status (from harmful organisms), for *D. vitifoliae*, *L.*
299 *decemlineata* and the bark beetle *Ips sexdentatus* under the European Union Plant Health Law
300 (Regulation (EU) 2016/2031 & (EU) 2019/2072). *Ips sexdentatus* was present on the longer list of IAS
301 that were reviewed, but with moderate scores for chance of arrival and establishment
302 (supplementary information 2) and hence not present within a ranked list. *Daktulosphaira vitifoliae*
303 and *L. decemlineata* occur on our priority list for economic impact. As such, measures are needed to
304 avoid the introduction of these pests (e.g. restrictions on movement of commodities, surveys) and to
305 ensure their eradication if found present.

306 Five species were selected from the top 20 human health and economic impact lists representing a
307 range of taxa and environments, for further discussion in the paper. We highlight where developing
308 communication campaigns around their pathways of introduction could raise awareness of the
309 threat these IAS pose to human health and economies across Cyprus. Raising awareness of the
310 impacts of IAS is, and will continue to be, an important part of the management of the introduction,
311 spread and impact of species that cause negative impacts (Booy et al. 2017). When communicating
312 information on IAS, it is important to use clear messaging from the project onset and throughout the
313 duration of programmes (Davis et al. 2018). Campaigns such as the “Check, Clean, Dry”, designed to
314 communicate information and so decrease the spread of freshwater IAS have been widely
315 implemented (Defra 2010). Public perception of management options can be counter to the need to
316 control IAS (Hine et al. 2015, Novoa et al. 2017, Crowley et al. 2019, Shackleton et al. 2019) and so it
317 is critical to include stakeholders, including the public, in the development of communication
318 campaigns. There are a number of Europe-wide initiatives including the COST Action Alien CSI
319 (https://alien-csi.eu/) which will be informative for the development of communication campaigns
320 to raise awareness about the IAS identified through this study.

Increased awareness would be beneficial for informing prevention and early-warning strategies across all IAS, however it is likely that campaigns targeted at specific IAS or, indeed, specific relevant sectors and stakeholders will be most effective (Davis et al. 2018). Here we provide representative examples of the IAS prioritised within the top 20 in one or both of the lists (human health and economic impacts), highlighting the breadth of taxa, environments and introduction pathways (Figure 4). CBD Level I and II (subcategory) pathways (CBD 2014, Harrower et al. 2018) are used throughout when describing pathways of introduction.

Parthenium hysterophorus

Parthenium hysterophorus, a plant originally from Mexico, Central and South America (ISSG 2010), was ranked in the top 20 in both the human health and economic impacts lists. *Parthenium hysterophorus*, an IAS of Union concern, has had large impacts on human health where it causes breathing difficulties and allergenic reactions in humans (Patel 2011). It can kill cattle and contaminate meat and milk, reducing the quality (Lakshmi and Srinivas 2007), and so also has economic impacts (McConnachie et al. 2011). Notably it is present in Israel which has similar climatic conditions to Cyprus. At the time of the workshop, there were 28 direct flights per week between Cyprus and Israel. This IAS was predicted to arrive through *luggage / equipment* (in particular tourism), as a *seed contaminant*, on *machinery / equipment* and through *transportation of habitat material (soil, vegetation, wood etc.)*; consequently raising awareness for these pathways would be valuable. We recommend developing collaborative campaigns with key industry partners, such as horticultural organisations, to increase biosecurity awareness around ornamental plants and seed contaminants, applying the European Code of Conduct on Horticulture and IAS (EPPO 2009). The European Code of Conduct, aimed towards the tourism and industry sectors, gives five recommendations for reducing the risk of IAS arrival (Scalera 2017).

Mosquitoes

Five mosquito IAS were included within the top 20 lists of IAS with the potential to adversely affect human health and economies. *Aedes aegypti* is native to Asia, *Ae. albopictus* is native to south east Asia, *Ae. flavopictus* is native to north east Asia, *Ae. japonicus* native to eastern Asia. *Culex quinquefasciatus* has uncertain origins with both Africa and Asia being possible (Fonseca et al. 2006). All these mosquito IAS are capable of reducing tourism through nuisance biting but more seriously can be vectors of human disease such as dengue, yellow fever, chikungunya and Zika (Smith et al. 2016). These IAS were identified predominantly to arrive as *hitchhikers in or on airplanes* and *hitchhikers in or on ships / boats*, in *vehicles* and for the *Aedes* mosquitoes through *contaminant on plants* pathways as this species lay their eggs on plant stems e.g. *Aedes albopictus* and lucky bamboo *Dracaena sanderiana* (Hofhuis et al. 2008). On contact with water, either during transit, or on arrival at the destination, the eggs develop into larvae and ultimately hatch into adult mosquitoes. These plants are predominantly introduced to countries via nurseries. Mosquito awareness campaigns, as well as following the guidance outlined in Martinou et al. (2020) for wetland management, could focus on these pathways supported through checks and signposting at airports and ports of arrival such as those carried out in New Zealand (Young 2003) as well as within the horticulture industry.

Daktulosphaira vitifoliae

Daktulosphaira vitifoliae, a small insect in the Order Hemiptera, originally from North America, was agreed to be of highest concern from the perspective of economic impacts in the context of Cyprus and is regulated in Plant Health Regulation (EE) 2016/2031. Cyprus is one of the few countries that uses traditional European vine root stock for growing grapes (Myrianthousis 1980), whereas in most parts of Europe, due to the presence and subsequent damage in the late 19th century of *D. vitifoliae*, American root stock is used (Granett et al. 1996). If this IAS arrived into Cyprus, there would be devastating effects, both culturally and economically to the wine production of the country. As such, it was ranked number one in the list of IAS anticipated to have a negative impact economies. Alongside strict biosecurity protocols, efforts campaigning for awareness around this species should

370 focus on *Transport – contaminant pathways* (such as *contaminant nursery material* and *contaminant*
371 *on plants*). As with *P. hysterophorus* and for the *Aedes* mosquitoes, working closely with the
372 horticultural industry, as well as with the agricultural industry area would support this messaging.

Procyon lotor

Procyon lotor is listed as an IAS of Union concern, and was included within the top 20 list of species with the potential to affect human health and within the top 50 for affecting economies. This species was also listed within the top 20 IAS to arrive, establish and impact biodiversity and ecosystem services (Peyton et al. 2019). *Procyon lotor*, originally from Central and North America, is found throughout Europe in the wild having escaped or been deliberately released from collections and is spreading in the Mediterranean (García et al. 2012, Mori et al. 2015, Lassnig et al. 2020). They were deliberately released for fur farming and hunting in Germany and the former USSR in the 1920s and 1930s (Aliev and Sanderson 1966, Lutz 1984). *Procyon lotor* is a versatile predator and can vector wildlife diseases and zoonosis, including rabies and raccoon roundworm *Baylisascaris procyonis* (Beltrán-Beck et al. 2012). *Procyon lotor* is an IAS identified as being traded in the pet trade. In terms of arrival to Cyprus, inclusion in the IAS of Union concern, Article 7 of the EU Regulation 1143/2014 means that restrictions for import, movement and trade have been in place since being listed in 2016. It is worth noting that, although trading the IAS is illegal, private owners who kept *P. lotor* as a companion animal before it was added as an IAS of Union concern are allowed to keep them under confinement. A risk of unintentional escape or intentional release is still possible however from private keepers or zoos, and such a case was documented before 2016 in the Akrotiri area in Cyprus and the animal was removed from the wild by the Game and Fauna Service. As such, *P. lotor* is predicted as most likely to arrive as an escape from confinement through the *botanical garden / zoos and aquaria (excluding domestic aquaria)*, the *pet / aquarium / terrarium species (including live food for such species)* and *other escape from confinement* pathways. Campaigns co-designed with the pet trade would support reducing the risk of escape or release.

Plotosus lineatus

Plotosus lineatus, native in the Red Sea, was identified as having the potential to impact both human health and economies; notably it had also previously been identified as a potential threat to

biodiversity and ecosystems. *Plotosus lineatus* produces a venomous hemolytic neurotoxin and can cause serious injury associated with infections and severe clinical manifestations as well as impacting economies through tourism and fisheries declines. It has been found along the Israel (Golani 2002, Galil 2007) and Turkish coasts (Doğdu et al. 2016) and is considered to be one of the 100 "Worst Invasives" in the Mediterranean sea (Streftaris and Zenetos 2006). This IAS entered the Mediterranean through the Lessepsian migration route via the Suez Canal, a major source of many of the invasive alien marine species in the Mediterranean. A full risk assessment of the species (Galanidi et al. 2019) led to its inclusion in the list of IAS of Union concern (EU, 2014). This IAS was predicted to arrive in Cyprus marine area through *natural dispersal*, through *interconnected waterways / seas / basins*, *pet / aquarium / terrarium species (including live food for such species)* and *research and ex-situ breeding (in facilities)*. As with *P. lotor*, inclusion on the IAS of Union concern means that this species is banned from being placed in the market, transported, kept or bred in contained holdings but can be kept for its natural life in the domestic environment if already purchased. In addition, this species could be kept within laboratories within the EU for research. A permit would be required under Article 8 of the EU Regulation 1143/2014 for research purposes. *Escape from confinement* through both these pathways are considered possible and hence included. With the exception of northern brown shrimp *Penaeus aztecus*, all marine IAS identified were of Indo-Pacific origin which are predicted to arrive through the pathway *Corridor* (CBD 2014, Harrower et al. 2018), which in the case of the Mediterranean refers to the Suez Canal. The Suez Canal, just under 400 nautical miles south of Cyprus, provides a gateway for major shipping routes to the Red Sea, with over 18,000 vessels carrying more than 980 M tonnes of cargo through the canal annually (Suez Canal Authority 2020). The creation and subsequent widening of the Suez Canal has resulted in the increasing transfer of marine species between the Red Sea and the Mediterranean Sea, with large ecological and economic impacts and there have been calls to use the brine output from planned desalination plants along the canal to create an effective salinity barrier to halt these invasions (Galil et al. 2017).

There are many challenges associated with managing established IAS in the marine environment (Russell et al. 2017) and feasibility of eradicating marine IAS is low (Booy et al. 2017), therefore, early reporting of new IAS is critical to inform mitigation strategies (Zenetos et al. 2019) and public awareness campaigns are important in the role of education and management of marine IAS (Giakoumi et al. 2019).

Conclusion

Horizon scanning to prioritise species with the potential to have negative impacts on human health or economies, is an important first step in IAS decision-making and specifically informing targeted surveillance and enabling contingency planning for the management of IAS (Shine et al. 2010, Caffrey et al. 2014, Roy 2015). Prioritised lists of IAS not yet present within a region can support biosecurity teams in implementing surveillance for early warning systems (Martinou et al. 2020) at borders, such as ports and airports, and at key hubs, such as garden centres and pet shops. Such lists are also useful for developing action plans to tackle important pathways of introduction and spread, a key component of which is the drafting targeted communication and awareness campaigns for the public around It is critical that risk communication is developed collaboratively to ensure maximum engagement from relevant stakeholders and communities. Collaborations among all stakeholders, ensuring shared goals and understanding between citizen scientists, policy makers and researchers, is critical to informing the development of IAS decision support tools and ultimately supporting biodiversity conservation (Vanderhoeven et al. 2015, Groom et al. 2019).

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451 The Darwin Initiative project “RIS-Ký” (http://www.ris-ky.info) includes a work package on capacity
452 building developing citizen science approaches for collecting data on interactions of pollinators with
453 invasive alien species on the island of Cyprus.

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