Biol Invasions (2026) 28:41
https://doi.org/10.1007/s10530-025-03729-8

ORIGINAL PAPER

Multiple introductions of invasive alien species on a Mediterranean Island predicted by horizon scanning

Angeliki F. Martinou · Jakovos Demetriou · Ioanna Angelidou · Nicolaos Kassinis · Anthemis Melifronidou · Jodey M. Peyton · Helen E. Roy · Alexander N. G. Kirschel

Received: 30 July 2025 / Accepted: 3 December 2025

Abstract In 2017 and 2019 two horizon scan workshops were undertaken for the island of Cyprus, which focused on making predictions about the invasive alien species (IAS) most likely to arrive and impact biodiversity, human health and the economy. Herein, we assess the species lists derived from these two horizon scans and consider the accuracy of the predictions so far. In less than ten years, 26 new IAS were found in Cyprus, 10 out of which were predicted to arrive by the horizon scans. Eight introduced IAS were ranked as high risk during the horizon scanning process. Horizon scanning helped raise awareness amongst the authorities, scientists and the public, leading in some cases to a rapid response by the competent authorities to control the arrival. We conclude that horizon scanning is a useful process that can inform contingency planning and action. Furthermore, it facilitates communication between IAS experts, policy makers and society, encouraging active engagement and raising awareness regarding the importance of early warning, rapid response

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10530-025-03729-8.

A. F. Martinou · J. Demetriou · I. Angelidou
Laboratory of Vector Ecology and Applied Entomology, Joint Services Health Unit Cyprus, BFC RAF Akrotiri, BFPO 57, Akrotiri, Cyprus

A. F. Martinou · J. Demetriou · I. Angelidou
Enalia Physis Environmental Research Centre, Acropoleos 2, 2101 Aglantzia, Nicosia, Cyprus

A. F. Martinou
Climate and Atmosphere Research Centre/Care-C, The Cyprus Institute, Athalassa Campus, 20 Konstantinou 59 Kavafi Street, 2121 Aglantzia, Nicosia, Cyprus

J. Demetriou
Department of Ecology and Systematics, Faculty of Biology, National and Kapodistrian University of Athens, Athens, Greece

I. Angelidou
Department of Environment, School of Environment, Ionian University, 29100 Zakynthos, Greece

N. Kassinis
Game and Fauna Service, Ministry of Interior, 1453 Nicosia, Cyprus

A. Melifronidou
Department of Agriculture, Ministry of Agriculture, Rural Development and Environment, Plant Health and Marketing Standards of Agricultural Products, Sector, Louki Akrita Avenue, 1412 Nicosia, Cyprus

J. Peyton · H. E. Roy
UK Centre for Ecology & Hydrology, Wallingford, England OX10 8BB, UK

J. Peyton
UKOTs Conservation Forum, 110 Nottingham Road, Stapleford, Nottingham NG9 8AR, UK

J. Peyton
Biodiversity, Ecology, and Conservation Group, IIASA, Laxenburg, Austria

Published online: 31 January 2026

and management of IAS. We propose that the horizon scanning process for the island of Cyprus is repeated regularly, recognizing the ongoing increase in the number of new IAS arriving year on year.

Περίληψη Το 2017 και το 2019 πραγματοποιήθηκαν δύο εργαστήρια σάρωσης ορίζοντα (horizon scanning – μια μέθοδος ανίχνευσης μελλοντικών τάσεων) για την Κύπρο, τα οποία επικεντρώθηκαν στην πρόβλεψη των χωροκατακτητικών ξένων ειδών (ΧΞΕ) που είναι πιο πιθανό να φτάσουν, να εγκατασταθούν και να επηρεάσουν τη βιοποικιλότητα, την ανθρώπινη υγεία και την οικονομία. Στην παρούσα εργασία, αξιολογούμε τους καταλόγους ειδών που προέκυψαν από αυτές τις δύο ανιχνεύσεις μελλοντικών τάσεων και εξετάζουμε την ακρίβεια των μέχρι στιγμής προβλέψεων. Σε λιγότερο από δέκα χρόνια, εντοπίστηκαν 26 νέα ΧΞΕ στην Κύπρο, 10 από τα οποία είχαν προβλεφθεί ότι θα φτάσουν από τις πιο πάνω ανιχνεύσεις. Οκτώ εισαχθέντα ΧΞΕ κατατάχθηκαν ως υψηλού κινδύνου κατά τη διαδικασία ανίχνευσης μελλοντικών τάσεων. Η σάρωση ορίζοντα συνέβαλε στην ευαισθητοποίηση των αρχών, των επιστημόνων και των πολιτών, οδηγώντας σε ορισμένες περιπτώσεις σε ταχεία αντίδραση των αρμόδιων αρχών για τον έλεγχο της άφιξης των ειδών. Εν κατακλείδι, η σάρωση ορίζοντα είναι μια χρήσιμη διαδικασία που βοηθά στον προγραμματισμό και την προετοιμασία σχεδίων δράσης. Επιπρόσθετα, διευκολύνει την επικοινωνία μεταξύ των εμπειρογνωμόνων για τα ΧΞΕ, των υπευθύνων χάραξης πολιτικής και της κοινωνίας, ενθαρρύνοντας την ενεργό συμμετοχή και αυξάνοντας την ευαισθητοποίηση σχετικά με τη σημασία της έγκαιρης προειδοποίησης, της ταχείας αντίδρασης και της διαχείρισης των ΧΞΕ. Προτείνουμε όπως η σάρωση ορίζοντα για το νησί της Κύπρου επαναλαμβάνεται τακτικά, αναγνωρίζοντας τη συνεχή αύξηση του αριθμού των νέων ΧΞΕ που φτάνουν κάθε χρόνο.

H. E. Roy
Centre for Ecology and Conservation, University of Exeter, Penryn, Cornwall, England TR10 9FE, UK

A. N. G. Kirschel (✉)
Department of Biological Sciences, University of Cyprus, PO Box 20537, 1678 Nicosia, Cyprus
e-mail: kirschel@ucy.ac.cy

Keywords Alien species · Cyprus · Horizon scanning · Invasive species · Non-native · Early warning · Detection · Management · Public engagement

Introduction

Invasive alien species (IAS) are primary drivers of biodiversity loss globally, alongside land and sea-use change, direct exploitation of organisms, climate change, and pollution (IPBES 2019). Reports on IAS global economic costs over the last 50 years estimate that they are responsible for a minimum of US$1.288 trillion in losses, a number that is steadily rising over time (Diagne et al. 2021; Roy et al. 2024a). Prevention is the most cost-effective approach to managing IAS and can be achieved through pathway management, including effective import controls, border biosecurity and quarantine services and facilities, but this requires long-term resourcing and capacity-building at national and international level (Roy et al. 2024a). When prevention fails, eradication or containment can work in specific contexts (IPBES 2023).

Preventing the arrival of new IAS underpins the EU Regulation 1143/2014 (hereafter EU Regulation), which obliges Member States to ensure there are measures to prevent or manage the introduction and spread of IAS species of Union Concern (the Union list). The EU Regulation includes a list of IAS of Union Concern but also encourages the development of IAS lists of regional and national concern. Moreover, it provides a legal basis for Member States to undertake action (i.e., emergency measures) on any new IAS. For preventive measures to be effective, targeted early warning and rapid response systems are needed, informed by predictions about which species are likely to arrive at a new location at a local, regional or national scale (Arianoutsou et al. 2023; Carboneras et al. 2018; de Groot 2020). The use of horizon scanning approaches based on data-driven expert knowledge is a method used to predict IAS that are likely to arrive, establish, spread and negatively impact nature and people (Roy et al. 2014). Horizon scans targeting IAS have been conducted under different geographical contexts e.g. at the European level

(Nunes et al. 2025; Roy et al. 2019a) or country level [Great Britain (Roy et al. 2014), Cyprus (Peyton et al. 2019), Greece (Martinou et al. unpublished data), Ireland (Lucy et al. 2020); Italy (Bertolino et al. 2020); Spain (Cano-Barbacil et al. 2023), United Kingdom Overseas Territories (Roy et al. 2019b; Dawson et al. 2023) and Antarctica (Hughes et al. 2020)]. Horizon scanning approaches have been used to consider impacts of IAS on plant health (Kenis et al. 2022; Mulema et al. 2022) or human health and the economy (Peyton et al. 2020). They also focus on different realms, for example, the marine realm (Tsiamis et al. 2020), inland waters (Oficialdegui et al. 2023) and protected areas (Adriaens et al. 2022).

The implementation of the EU IAS Regulation (EU 1143/2014) within the Republic of Cyprus in 2019 [N. 120(I)/2019], as well as concerns over IAS by different research groups called for action. Two horizon sc anning exercises were undertaken in 2017 and 2019 (Peyton et al. 2019, 2020). Peyton et al. (2019) focused on IAS that are likely to arrive and impact biodiversity and Peyton et al. (2020) on IAS that are likely to arrive within a decade and impact human health and the economy. Here, we revisit the outcomes of these horizon scans and specifically document the IAS that have recently arrived in Cyprus.

Materials and methods

Data on biological invasions in Cyprus were obtained from the Cyprus Database of Alien Species (CyDAS—https://ris-ky.info/cydas) (Demetriou et al. 2025) as well as from published (literature and press releases) and unpublished records (including consultation with experts) to locate any species' records that had been published after the completion of the two horizon scanning exercises in 2017. For this, we catalogued the publication years of first detection for all species recorded during the timeframe 2017 – 2023 (Suppl. File 1).

Subsequently, we cross-checked species on the database with other datasets and publications on IAS checking the arrival of species listed in the 100 world's worst invasive species (GISD 2024), IAS of EU Concern (EU 2016/1141; EU 2017/1263; EU 2019/1262; EU 2022/1203), species in the European and Mediterranean Plant Protection Organization (EPPO) lists A1, A2 and alert list (EPPO 2024), species denoted as having some unnamed "Impact" in the European Alien Species Information Network (EASIN) (EASIN 2024), species for which fact sheets are available on the European Centre for Disease Prevention and Control (ECDC) website, as well as whether the listed species were predicted to arrive, establish and have a negative impact on the biodiversity, human health and economy of Cyprus (Peyton et al. 2019, 2020). In addition, we examined the complete datasets of species assessed during the horizon scanning exercises (Peyton et al. 2019, 2020 – suppl. files) to assess species that were detected during the timeframe 2017 – 2023 as well as species included in the horizon scanning datasets for which prior knowledge of introductions was missing/overlooked.

Results

Our literature search showed that 183 alien species were detected in Cyprus from 2017 – 2023. Out of these species, a total of 31 alien species were included in any list of invasive alien species and/or were predicted by the horizon scanning exercises amongst the top 100, top 20, and top 50 to affect biodiversity, human-health and the economy (Suppl. File 1). Crosschecking these 31 taxa with databases on impacts, 26 alien species are classified as IAS, due to their negative impacts on biodiversity and in some cases also human health or economic sectors such as agriculture (Table 1) (i.e. excluding *Dorvillea similis*, *Heliotropium curassavicum*, *Matuta victor*, *Myra subgranulata*, *Synanceia verrucosa*—no impacts on any checked database but predicted during horizon-scans). These 26 IAS are included on the European Plant Protection Organization (EPPO) pest lists (6), lists of the world's worst IAS (3), IAS of EU Concern (4), species with "Impact" according to the European Alien Species Information Network (EASIN) (23), and European Centre for Disease Prevention and Control (ECDC) factsheets (2) for their negative impacts (Table 1). Ten of these 26 IAS species were predicted to arrive, establish and impact biodiversity, human-health and the economy in Cyprus according to Peyton et al. (2019, 2020), scoring amongst the top 100, 20, 50 to affect biodiversity, human-health and

Table 1 Introduction of 26 IAS to Cyprus from 2017–2023 included in one or more lists for their negative impacts on biodiversity, human health or economic sectors i.e. the list of IAS of Union Concern, the world's worst 100 IAS list, the European Plant Protection Organization (EPPO) A1 and A2 lists, the European Centre for Disease Prevention and Control (ECDC) factsheets as well as those indicated by the European Alien Species Information Network (EASIN) database as having some "impact" (devoid of further data). Their inclusion in Peyton et al. (2019, 2020—suppl. files) within the top 100, 20 and 50 alien species with the potential to threaten biodiversity, human health and the economy, respectively, is denoted alongside a link to their species profile on the Cyprus Database of Alien Species (CyDAS)

Species	IAS of Union Concern	World's worst 100 IAS	EPPO A1 list	EPPO A2 list	ECDC factsheets	"Impact – YES" EASIN	Predicted by Peyton et al. (2019, 2020)	CyDAS info
	4	3	2	4	2	23	10	
Acridotheres tristis	Yes	Yes				Yes	Yes	https://ris-ky.info/species/acridotheres-tristis
Aedes aegypti					Yes		Yes	https://ris-ky.info/species/aedes-aegypti
Aedes albopictus		Yes			Yes	Yes	Yes	https://ris-ky.info/species/aedes-albopictus
Amathia verticillata						Yes	Yes	https://ris-ky.info/species/amathia-verticillata
Austrocylindropuntia subulata						Yes	Yes	https://ris-ky.info/species/austrocylindropuntia-subulata
Bursatella leachii						Yes		https://ris-ky.info/species/bursatella-leachii
Cenchrus setaceus	Yes					Yes		https://ris-ky.info/species/cenchrus-setaceus
Chasmanthe aethiopica						Yes		https://ris-ky.info/species/chasmanthe-aethiopica
Clavelina oblonga						Yes		https://ris-ky.info/species/clavelina-oblonga
Diaphorina citri			Yes					https://ris-ky.info/species/diaphorina-citri
Drosophila suzukii				Yes		Yes		https://ris-ky.info/species/drosophila-suzukii

Table 1 (continued)

Species	IAS of Union Concern	World's worst 100 IAS	EPPO A1 list	EPPO A2 list	ECDC factsheets	"Impact – YES" EASIN	Predicted by Peyton et al. (2019, 2020)	CyDAS info
Hylocereus undatus						Yes		https://ris-ky.info/species/hylocereus-undatus
Leonotis nepetifolia						Yes		https://ris-ky.info/species/leonotis-nepetifolia
Leptoglossus occidentalis						Yes	Yes	https://ris-ky.info/species/leptoglossus-occidentalis
Myoporum laetum						Yes		https://ris-ky.info/species/myoporum-laetum
Opogona sacchari				Yes		Yes		https://ris-ky.info/species/opogona-sacchari
Paratrechina longicornis						Yes		https://ris-ky.info/species/paratrechina-longicornis
Phyllorhiza punctata						Yes	Yes	https://ris-ky.info/species/phyllorhiza-punctata
Plotosus lineatus	Yes					Yes	Yes	https://ris-ky.info/species/plotosus-lineatus
Spartium junceum						Yes		https://ris-ky.info/species/spartium-junceum
Spodoptera frugiperda				Yes				https://ris-ky.info/species/spodoptera-frugiperda
Spodoptera litura			Yes			Yes		https://ris-ky.info/species/spodoptera-litura
Styela plicata						Yes		https://ris-ky.info/species/styela-plicata

Table 1 (continued)

Species	IAS of Union Concern	World's worst 100 IAS	EPPO A1 list	EPPO A2 list	ECDC factsheets	"Impact – YES" EASIN	Predicted by Peyton et al. (2019, 2020)	CyDAS info
Tradescantia fluminensis						Yes	Yes	https://ris-ky.info/species/tradescantia-fluminensis
Tropaeolum majus						Yes		https://ris-ky.info/species/tropaeolum-majus
Wasmannia auropunctata	Yes	Yes				Yes	Yes	https://ris-ky.info/species/wasmannia-auropunctata

the economy, respectively (Peyton et al. 2019, 2020—suppl. files).

Regarding the nine plant species in Table 1, these are common within the plant trade and were most certainly present on Cyprus yet horizon scanning exercises also dealt with their establishment and impacts. Nevertheless, at the time of the horizon scanning exercises (prior to 2017), there was no knowledge of their escape from cultivation but reports of casual, escaped or naturalized plants appear later in the scientific literature (Suppl. File 1). Thus, it is possible that at the time of the original horizon scans, these plants were already present in the wild, either as casual records (and therefore eligible for inclusion on the horizon scan list) or established species but it is also possible they have escaped since the scans.

Of these 10 IAS that arrived (Table 1—predicted by Peyton et al. 2019, 2020), seven (i.e. *Acridotheres tristis, Aedes aegypti, Aedes albopictus, Amathina verticillata, Plotosus lineatus, Phyllorhyza punctata,* and *Wasmannia auropunctata*) scored high during the horizon scanning exercises. We then added to the list of IAS the venomous stonefish *Synanceia verrucosa* due to its high score and invasiveness, despite not being included in any of the aforementioned impact lists in Table 1. These eight taxa were predicted within the top 20 IAS to arrive, establish and impact the island during horizon scanning exercises assessing 225 (Peyton et al. 2019) and 352 (Peyton et al. 2020) species, respectively (Table 2).

A further 10 species (including *Austrocylindropuntia subulata*, *Leptoglossus occidentalis* and *Tradescantia fluminensis* from Table 1) were detected but received lower scores during the horizon scans for their potential impact on biodiversity, human health and socioeconomic impacts (Table 3), and consequently were not included on the high priority lists of the horizon scans (Table 2, Peyton et al. 2019, 2020). Although, *Austrocylindropuncta subulata*, *Dorvillea similis*, *Leptoglossus occidentalis*, *Matuta victor*, *Myra subgranulata*, and *Tradescantia fluminensis* scored within the top 100 species to arrive, establish and impact native biodiversity (Peyton et al. 2019), these species received lower scores, ranking them between 50th—100th position (Peyton et al. 2019—suppl. file). *Heliotropium curassavicum* scored highly during the horizon scanning exercises due to its potential impacts on native biodiversity, i.e. competition with other species (Peyton et al. 2019—suppl. file). The species is widespread in the Mediterranean and was first reported from Cyprus in 2018 (Charilaou 2018). According to Charilaou (2018) "the population […] is very small (about 50 plants), but seems to be well established", while "it is likely to occur in other coastal places and saline ground in Cyprus" recommending further monitoring (Fig. 1). Nevertheless, the plant is classified in the Flora of Cyprus website (Hand et al. 2011) as a naturalized non-invasive species and no data on its impacts were retrieved. Thus, it was not included in the priority IAS list of species that were correctly predicted to arrive (Table 2).

Table 2 Details regarding the establishment status, the year of detection, sources of information and whether they are included in the EU IAS regulation (Union list) for the eight species that received the highest scores (i.e. in top 20) during the Horizon Scanning Exercises and subsequently arrived on the island (Peyton et al. 2019, 2020)

	Species	Common name	Status	Year of Detection	Source of Information	Predicted to arrive by Peyton et al. (2019) or Peyton et al. (2020)	EU IAS Regulation (Yes or No)	CyDAS info
1	*Acridotheres tristis* (Linnaeus, 1766)	Common myna	Extirpation measures in progress	2022	Magory Cohen et al. (2022)	Peyton et al. (2019)	Y	https://ris-ky.info/species/acridotheres-tristis
2	*Aedes aegypti* Linnaeus, 1762	Yellow Fever mosquito	Unknown	2022	CNA/Ministry of Health (2022)	Peyton et al. (2020)	N	https://ris-ky.info/species/aedes-aegypti
3	*Aedes albopictus* (Skuse, 1894)	Asian tiger mosquito	Established	2022	Christou et al. (2023); Martinou et al. (2023)	Peyton et al. (2020)	N	https://ris-ky.info/species/aedes-albopictus
4	*Amathia verticillata* (Delle Chiaje, 1822)	Spaghetti Bryozoan	Unknown	2016	Ulman et al. (2017)	Peyton et al. (2019)	N	https://ris-ky.info/species/amathia-verticillata
5	*Phyllorhiza punctata* von Lendenfeld, 1884	Australian spotted jellyfish	Unknown	2022	Kaminas et al. (2022)	Peyton et al. (2020)	N	https://ris-ky.info/species/phyllorhiza-punctata
6	*Plotosus lineatus* (Thunberg, 1787)	Striped eel fish	Not established	2022	Beton and Huseyinoglu (2022)	Peyton et al. (2019), (2020)	Y	https://ris-ky.info/species/plotosus-lineatus
7	*Synanceia verrucosa* Bloch & Schneider, 1801	Reef Stonefish	Not established	2020	Akbora et al. (2021)	Peyton et al. (2020)	N	https://ris-ky.info/species/synanceia-verrucosa
8	*Wasmannia auropunctata* (Roger, 1863)	Little fire ant	Established	2022	Demetriou et al. (2022), (2023a)	Peyton et al. (2020)	Y	https://ris-ky.info/species/wasmannia-auropunctata

An additional 17 species had occurred in Cyprus prior to the horizon scanning exercises but were still assessed in them because knowledge of their arrival had not been disseminated and checklists of non-native species on the island were not fully up to date at the time (Table 4).

Discussion

Prevention is the least costly and most effective option for reducing the threats from biological invasions (Roy et al. 2024b). From 2017 to 2023, there were publications on 183 novel alien species reported from Cyprus out of which 26 were categorised as IAS because of evidence of their negative impacts

Table 3 Additional alien species detected in the last seven years that were assessed by Peyton et al. (2019, 2020) but were not included on the priority lists of species because they received lower scores for their potential impact

No	Species	Received impact score			Assessed by:	Reference(s)
		Biodiversity	Human health	Economy		
1	*Heliotropium currasavicum*	100	–	–	Peyton et al. (2019)	https://ris-ky.info/species/heliotropium-curassavicum
2	*Tradescantia fluminensis*	60	–	–	Peyton et al. (2019)	https://ris-ky.info/species/tradescantia-fluminensis
3	*Leptoglossus occidentalis*	75	–	–	Peyton et al. (2019)	https://ris-ky.info/species/leptoglossus-occidentalis
4	*Matuta victor*	64	–	–	Peyton et al. (2019)	https://ris-ky.info/species/matuta-victor
5	*Austrocylindropuntia subulata*	60	20	–	Peyton et al. (2019, 2020)	https://ris-ky.info/species/austrocylindropuntia-subulata
6	*Dorville assimilis*	75	25	25	Peyton et al. (2019, 2020)	https://ris-ky.info/species/dorvillea-similis
7	*Myra subgranulata*	75	25	25	Peyton et al. (2019, 2020)	https://ris-ky.info/species/myra-subgranulata
8	*Spodoptera frugiperda*	–	9	27	Peyton et al. (2020)	https://ris-ky.info/species/spodoptera-frugiperda
9	*Thaumastocoris peregrinus*	–	12	36	Peyton et al. (2020)	https://ris-ky.info/species/thaumastocoris-peregrinus
10	*Zelus renardii*	–	16	16	Peyton et al. (2020)	https://ris-ky.info/species/zelus-renardii

on biodiversity, socioeconomic sectors, human- and plant health. The two horizon scans performed in Cyprus predicted 10 of these 26 species denoted as IAS through various databases (Table 1), that subsequently arrived and are known to have major impacts on biodiversity, human health and the economy such as common myna, two *Aedes* invasive mosquitoes, striped eel fish and little fire ant. Nevertheless, upon the addition of the stone fish *Synanceia verrucosa* and removal of *Austrocylindropuntia subulata*, *Heliotropium currasavicum*, *Leptoglossus occidentalis*, and *Tradescantia fluminensis*, eight highly-scoring priority IAS were effectively predicted and subsequently arrived (Table 2). The circumstances of their arrival, discovery and mitigation measures are discussed below.

The eight top-listing IAS correctly predicted to arrive in Cyprus by horizon scanning, their impacts and actions taken.

Of the terrestrial IAS predicted to arrive, the common myna (*Acridotheres tristis*) is one of the most important avian IAS globally with negative impacts on biodiversity and agriculture (Peyton et al. 2019; Magory Cohen et al. 2022). In Cyprus, the common myna was first observed in January 2022, with 11 individuals observed on the Akrotiri peninsula and close to Limassol port (Magory Cohen et al. 2022). Eradication measures were undertaken by SBAA Environment Department Wardens and the Game and Fauna Service, and 21 individuals had been culled by December 2024 (Nathanael 2024). The proximity of sightings to Limassol port, and the observation of groups of birds in the same area close to the port, following culling events are consistent with multiple biological invasions (Nathanael 2024), suggesting introduction has been ship mediated. The risks of repeated introductions of this species are thus extremely high.

Two of the predicted IAS were mosquitoes. The yellow fever mosquito, *Aedes aegypti*, previously eradicated from Cyprus in the 1930s (Aziz 1934, reported in Violaris et al. 2009), was discovered at Dromolaxia close to Larnaca international airport in 2022 (CNA/Ministry of Health 2022). A pilot

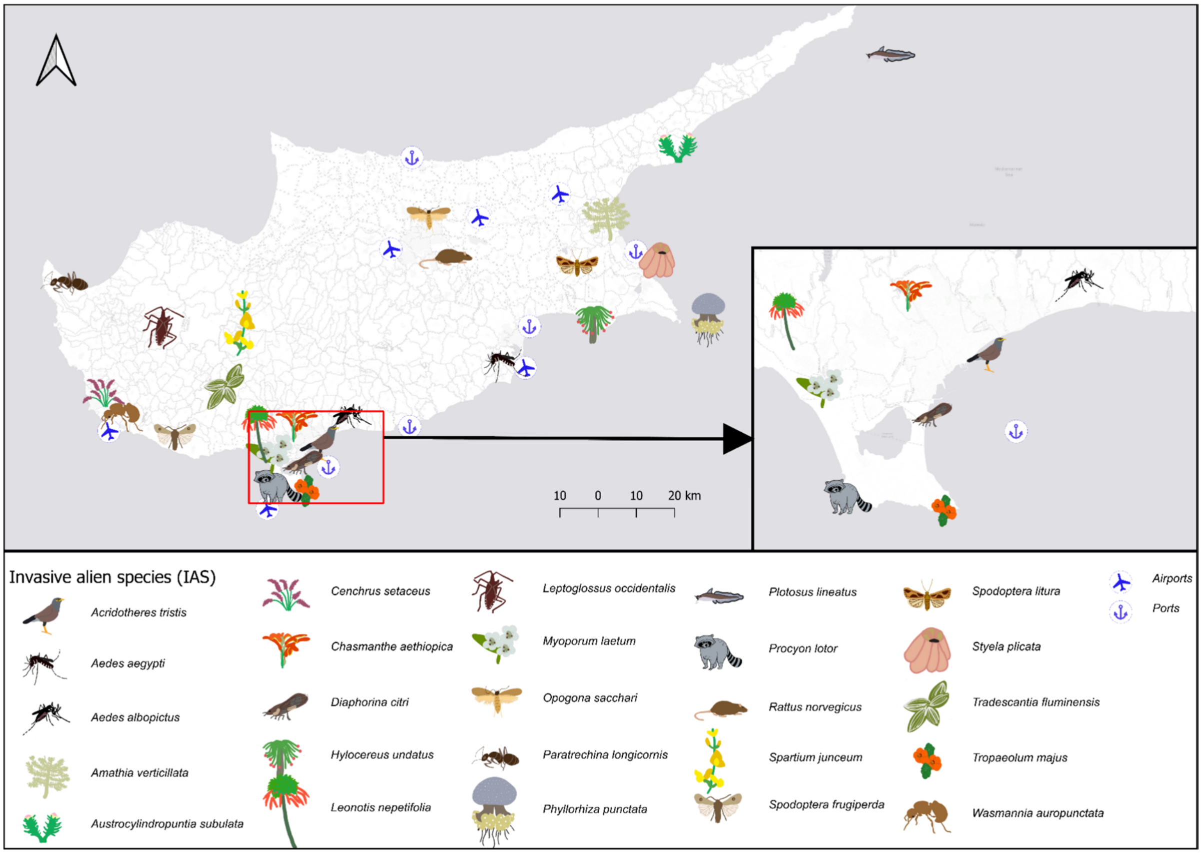

Fig. 1 Map of Cyprus illustrating where IAS in the legend were first located and recorded, with the inset focusing in on the Akrotiri peninsula and Limassol port area

project in 2023 to eradicate it used the Sterile Insect Technique (SIT) releasing batches of 100,000 sterile male yellow fever mosquitoes weekly in a test area roughly 0.5 km^2 in Kiti, close to the airport (IAEA 2023), but information on the success of this approach is lacking at this time. The Asian tiger mosquito *Aedes albopictus*, was the second invasive mosquito species recorded in Cyprus in 2022 (Christou et al. 2023). Citizen scientists provided regular feedback from six *Ae. albopictus*-positive locations in Limassol, revealing its rapid spread into new locations in the suburbs of Limassol and in Nicosia (A. Martinou unpublished data). Like *Ae.aegypti*, *Ae. albopictus* can cause diseases such as dengue, chikungunya, and Zika and suggests its potential impact on native biodiversity i.e. the native *Aedes cretinus* (Giatropoulos et al. 2024), a species also known to exist in Cyprus (Martinou et al 2016; Martinou et al. 2021). To date proposed interventions have proved unsuccessful (Vasquez et al. 2023), possibly due to control efforts focusing on public land and not private properties where *Ae. albopictus* breeds. As a result, *Ae. albopictus* continues to spread (Piccinno et al. 2025).

The little fire ant *Wasmannia auropunctata,* which is native to the Neotropics, but has invaded the Mediterranean, known from Israel, Spain and France (Vonshak and Ionescu-Hirsch 2009; Vonshak et al. 2010; Espadaler et al. 2018, 2020; Blight et al. 2024; Arcos et al. 2025; Pérez-Delgado et al. 2025). The little fire ant was first detected in Cyprus in 2022, likely unintentionally introduced through the plant trade, and since then its distribution on the island has increased based on extensive surveys (Demetriou et al. 2022, 2023a, unpubl. data). It is renowned for its adverse impacts on native biodiversity, human and animal health as well as the economy, amongst others displacing native arthropods from invaded areas, causing

Table 4 Species occurring in Cyprus prior to the horizon scanning that were assessed by Peyton et al. (2019) and Peyton et al. (2020). Column on establishment status follows the Cyprus Database of Alien Species (CyDAS) terminology

No	Species	Establishment status	Notes
1	*Atriplex nummularia*	Not Established	https://ris-ky.info/species/atriplex-nummularia
2	*Caulerpa taxifolia*	Established	https://ris-ky.info/species/caulerpa-taxifolia-var-distichophylla
3	*Corvus splendens*	Not Established	https://ris-ky.info/species/corvus-splendens
4	*Mustela nivalis*	Extinct	https://ris-ky.info/species/mustela-nivalis
5	*Parthenocissus quinquefolia*	Not Established	https://ris-ky.info/species/parthenocissus-quinquefolia
6	*Paulownia tomentosa*	Unknown	https://ris-ky.info/species/paulownia-tomentosa
7	*Penaeus semisulcatus*	Not Established	https://ris-ky.info/species/penaeus-semisulcatus
8	*Procyon lotor*	Not Established	https://ris-ky.info/species/procyon-lotor
9	*Prosopis juliflora*	Not Established	https://ris-ky.info/species/prosopis-juliflora
10	*Oreochromis niloticus*	Not Established	https://ris-ky.info/species/oreochromis-niloticus
11	*Oxyura jamaicensis*	Not Established	https://ris-ky.info/species/oxyura-jamaicensis
12	*Rattus norvegicus*	Established	https://ris-ky.info/species/rattus-norvegicus
13	*Solanum linnaeanum*	Established	https://ris-ky.info/species/solanum-linnaeanum
14	*Solenopsis geminata*	Not Established (doubtful record)	https://ris-ky.info/species/solenopsis-geminata
15	*Sus scrofa*	Exterminated	https://ris-ky.info/species/sus-scrofa
16	*Testudo graeca*	Established	https://ris-ky.info/species/testudo-graeca-ibera
17	*Trichomyrmex destructor*	Established	https://ris-ky.info/species/trichomyrmex-destructor

anaphylactic shocks, skin and eye problems, with management and eradication efforts being both challenging and costly (Lubin 1984; Wetterer and Porter 2003; Mbenoun-Masse et al. 2017; Rosselli and Wetterer 2017; Angulo et al. 2022; Kidon et al. 2022; Blight et al. 2024).

Several IAS found were marine organisms, including the Australian spotted jellyfish (*Phyllorhiza punctata*), native to the western Pacific Ocean, which has caused significant ecological and economic damage globally (Kaminas et al. 2022). It was first reported in February 2022 by a recreational diver through the citizen science platform “Is it alien to you? Share it!!!” (Kaminas et al. 2022). The striped eel catfish *Plotosus lineatus* is an Indo-Pacific reef-associated marine fish, inhabiting shallow coastal waters (FishBase 2025a). It was first recorded in the Mediterranean invading the Israeli coast (Edelist et al. 2012) and in Cyprus, ~ 17 specimens were caught by a fisherman off Rizokarpaso Peninsula in April 2022 (Beton et al. 2022). The reef stonefish *Synanceia verrucosa* Bloch & Schneider, 1801 is an alien stonefish caught and photographed in May 2020 by harpooners in Kumyalı in the north of Cyprus (Akbora et al. 2021). It primarily inhabits shallow rocky areas and is characterized as one of the world’s most venomous fish (FishBase 2025b). This species was not included in the IAS of EU Concern or the EASIN database as having any negative impact on native species and thus, was included in the horizon scan for its threat to human health only. Lastly, *Amathia verticillata*, a cryptogenic bryozoan thought native to the Caribbean Sea (Galil and Gevili 2014; Marchini et al. 2015; Nascimento et al. 2021), was recorded just before the first horizon scan. It was first recorded in Cyprus in 2016 by Ulman et al. (2017) but published after the first horizon scanning workshop, thus included therein. Although we could not trace further records from Cyprus, the species is expected to have spread since it is widely distributed within the Mediterranean Basin (Ferrario et al. 2018; Nascimento et al. 2021).

Importance of horizon-scanning and species inventories

A total of 17 species were already present in or reported from Cyprus prior to the horizon scanning exercises (Table 4), but knowledge of those occurrences had not been disseminated widely or had been overlooked at the time of the horizon scans. Amongst these, was the brown rat *Rattus* *norvegicus*. Although thought to have originated from Eastern Asia, it now has a cosmopolitan distribution and its impacts on the global economy are estimated at around 156.6 million US dollars during the last century (Diagne et al. 2023), with severe effects on native island biotas, including extinction of animals through predation and competition (Amori and Clout 2003; St Clair 2011; Harper and Bunbury 2015). Human health impacts of brown rats include spreading disease through the transmission of zoonotic bacteria, protozoa and viruses (Ryll et al. 2017; Galán-Puchades et al. 2021; Sabour et al. 2022). In Cyprus, its prior presence was not known to the wider community at the time of the first horizon scan (Peyton et al. 2019), and a record from 2019 in Nicosia had been described as the first occurrence (Hadjisterkotis et al. 2019, 2020). However, records as far back as 1985 have been uncovered (Hoppe 1985), with captures as part of studies performed in the early 2000s showing *R. norvegicus* to be common and widespread by then (Antoniou et al. 2010; Psaroulaki et al. 2010) and known by the time of the second horizon scan (Peyton et al. 2020). Similarly, horizon scanning prioritized the raccoon *Procyon lotor,* which is native to North America, but that has spread in Europe after escaping from fur farms, pet owners, and from introductions into the wild in the former Soviet Union in the early twentieth century (Bartoszewicz 2006). It is one of the most successful alien carnivores in Europe due to its high reproductive capacity, feeding habits and adaptive behaviour, preying on native species such as waterfowl, amphibians, rodents, reptiles and insects (Bartoszewicz 2006), and is a vector of parasites and diseases that risk native wildlife and humans alike. Again, a record of the raccoon was documented prior to the horizon scanning, in March 2011 in the Akrotiri peninsula in Cyprus, observed on a camera trap. The animal was captured by the Game and Fauna Service. Raccoons have also been captured from inland sites from the villages of Prodromos and Pareklissia in Limassol district, but also from within Nicosia municipality. These animals were likely kept as pets and then intentionally released or escaped from captivity. Furthermore, tortoises such as the assessed *Testudo graeca*, or its relative species *T. marginata*, were already reported during the 1980s (Demetropoulos and Lambert 1986; Hadjisterkotis and Reese 1994) but to-date records are rare. Data on year of first reporting of *Corvus splendens* (in 2011) and *Oxyura jamaicensis* (in 2011) had not been made publicly available and were obtained upon communication with BirdLife Cyprus, while both mammals *Mustela nivalis* and *Sus scrofa* were rightfully assessed as these species have gone extinct on the island (Hadjisterkotis 2000; Hadjisterkotis and Heise-Pavlov 2006; Rodrigues et al. 2016). Alien ant species *Solenopsis geminata* and *Trichomyrmex destructor* were first reported for Cyprus in 1997 and 1956 (Georghiou 1977; Collingwood et al. 1997), nevertheless, their presence was questioned by Salata et al. (2019) and knowledge of the absence of *S. geminata* and presence of *T. destructor* was widely disseminated after the horizon scanning exercises (Demetriou et al. 2023a). A number of alien plants e.g. *Atriplex nummularia*, *Parthenocissus quinquefolia*, *Paulownia tomentosa*, *Prosopis juliflora*, *Solanum linnaeanum* and marine organisms *Caulerpa taxifolia* and *Penaeus semisulcatus* had also been reported, with records not being widely disseminated.

These findings showcase the importance of the horizon scanning exercises in predicting the introduction of IAS and informing contingency planning as well as the importance of up-to-date species inventories of alien and IAS such as the CyDAS. Even in the case of the species that had already occurred unbeknownst to the participants of the horizon scanning exercises, the scans and resultant publications raised awareness of these IAS more widely, potentially aiding in their identification for appropriate mitigation. In addition to the IAS highlighted in the horizon scans, a further ten IAS species that had received lower scores in Peyton et al. (2019, 2020) were detected from 2017 to 2023 (Table 3). Three out of these 10 species are IAS according to EASIN, i.e. *Tradescantia fluminensis*, which was established prior to the second horizon scan thus not included therein (Peyton et al. 2020), *Leptoglossus occidentalis*, and *Austrocylindropuntia subulata,* while *Spodoptera frugiperda* is included in the EPPO A2 list. Of those, according to the National Plant Protection Organisation (NPPO) of Cyprus, *S. frugiperda* is being eradicated (https://gd.eppo.int/reporting/article-7667), however, citizen-science and data from biodiversity experts show a wide distribution on the island (iNaturalist 2025; Lepiforum 2025).

Further cases of note in relation to species predicted to arrive and impact the island's economy were the brown marmorated stink bug (*Halyomorpha halys*) and the Colorado potato beetle (*Leptinotarsa decemlineata*) that were ranked amongst the top 50 (Peyton et al. 2020). *Halyomorpha halys* was reported in Cyprus in May 2022, when a citizen scientist through the 'Bug Alert Cyprus' (https://martinoulab.weebly.com/bug-alert-cyprus.html) awareness raising campaign (Vétek et al. 2021) reported that they found a dead specimen in their luggage. Similarly, the Colorado potato beetle (*L. decemlineata*) was detected in 2010 by inspectors of the Department of Agriculture in a consignment of ware potatoes from Bulgaria, which immediately proceeded with its destruction, thus preventing its release into circulation, and maintaining the status of Cyprus as a protected zone in accordance with EU regulations. To this end, *Solanum tuberosum* L., i.e. the main host plant of *L. decemlineata,* may only enter Cyprus subject to special phytosanitary requirements for protected zones. As the first event (*H. halys*) concerned a dead individual and the second (*L. decemlineata*) a border interception, these species were not considered to have arrived and established. Nevertheless, these constitute important findings necessitating stronger control, participation of citizens in the scientific research of biological invasions as well as increased reporting and data-dissemination.

Communication, citizen science and management of IAS

The detection of IAS in many cases involves transportation through airports and seaports. Yet, none of the introduced IAS were reported at border crossings across the 'Green Line', the United Nations controlled buffer zone that extends 180 km across the island. The lack of records from the Green Line highlights the need for reporting, importance of cross-community collaboration across the island and a need to raise awareness to better inform border control staff and customs officers regarding IAS. Data on IAS detected during border controls and phytosanitary inspections could be shared to inform action and specifically raise awareness of potential introductions of IAS. Border inspections and pathway monitoring could be supported by local experts offering identification services for a variety of taxa. The horticultural industry is a major pathway for the introduction of alien plants (Hinsley et al. 2025), insects such as ants, including the invasive alien little fire ant (Demetriou et al. 2023a) that are often missed by border interceptions (Wong et al. 2023). Eradication and control actions across borders can also be a major challenge for invasive vertebrates, such as the common myna (Magory Cohen et al. 2022).

Communication is also essential among the various institutions and authorities discovering IAS and taking action. The horizon scans involved researchers as well as experts from government departments and thus these relevant authorities were informed on which species would potentially arrive on the island within a 10-year time frame. Communicating the outcomes of the horizon scanning beyond researchers and policy makers to professionals such as customs officers, fishers, ship crews, pet shop owners, and school teachers can aid the early detection of IAS.

Furthermore, early warning and rapid responses towards IAS increasingly depend on the commitment of citizen scientists to report observations of IAS of concern (Vanderhoeven et al. 2015; Price-Jones et al. 2022; Pocock et al. 2023). There are examples of several successful citizen science initiatives e.g. the Asian Hornet Watch (Hassall et al. 2025), EASIN and Mosquito Alert (Palmer et al. 2017) that run at national or European level. Best practice guides and courses for specific target groups such as school teachers (AlienCSI 2023; academy.europa.eu/courses/have-you-seen-an-alien) can aid those who wish to initiate citizen science projects focusing on IAS. In Cyprus, six IAS identified in the horizon scans were reported by citizen scientists. Through public participation, IAS records can be generated for species affecting biodiversity, such as the common myna (Nathanael 2024) and for those that affect human health e.g. the Asian tiger and yellow fever mosquitoes (Yetismis et al. 2022; Lühken et al. 2023). Indeed, artificial intelligence, computer vision or deep learning models could be used to automatically identify IAS from photographs collected by citizen scientists on platforms such as iNaturalist (Cardoso et al. 2024). Through such platforms, information could rapidly be conveyed to decision-makers who can take appropriate action (Roy et al. 2024b). Other tools such as environmental DNA (eDNA) can help detect introduced IAS that are difficult to detect otherwise, including freshwater or marine taxa (Holman et al. 2019; Rishan et al. 2023). Environmental DNA sampling could be adopted during school field study programs run by environment centers within protected areas in Cyprus. Provided that authorities can leverage these data, IAS early detection and response could be significantly enhanced.

Further benefits of the two horizon scan workshops were the networking opportunities and the sharing of information on IAS at the national and international level. This included updates to the CyDAS online database and the development of CyDAS species alert cards (Demetriou et al. 2025) and the ACE database (Alien to Cyprus Entomofauna) (Demetriou et al. 2023b). The two databases can assist monitoring and research, risk assessments, prioritization of IAS, management strategies and the establishment of rapid response/early warning systems. Future horizon scans will benefit from information on the most recent IAS horizon scanning in support of implementation of Regulation 1143/2014 prepared for the European Commission (Nunes et al. 2025), as well as impacts of IAS through the Global Impacts Dataset of Invasive Alien Species (GIDIAS) dataset compiled for the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Assessment on IAS (Bacher et al. 2025). GIDIAS provides information on the impacts of IAS on biodiversity but also on nature's contributions, economy and health. It can greatly assist experts who need to identify the highest risk species during horizon scans or prioritize actions and management plans for IAS at the early stage of introduction.

Conclusion

Overall, the horizon scanning was an important process to prioritize the emerging and most threatening IAS with the highest risk of introduction in Cyprus. As new IAS are continuously introduced it is important that horizon scanning is a dynamic process and that it is repeated within set time frames of 5–10 years. Pathway management plans and contingency planning at national level are a useful next step following horizon scanning. These plans could be shared widely at a local level with all stakeholders and authorities to allocate roles and responsibilities efficiently. Preparedness is key and it is essential that competent authorities should be made aware in a timely manner of the results of horizon scans, to build capacity and engage in further contingency planning. Furthermore, the active engagement of the communities through citizen science initiatives can greatly help scientists and the authorities towards the early detection of introduced IAS as well as on reporting the spread or the impacts of IAS.

Acknowledgements We thank the Akrotiri Environment Education Centre for hosting the horizon scans and the follow-up workshop. We thank all the participants of the workshop. The workshops were funded by the UK government through Darwin Plus DPLUS056, DPLUS088 and Darwin Plus Local DPL00014, and updating the Cyprus Database of Alien Species through Darwin Plus DPLUS124. DPLUS175 has been useful in providing a forum for exchange of information. We would also like to thank Eloise Springate for the IAS illustrations. Lastly, we would like the editor Deah Lieurance, Belinda Gallardo and one anonymous reviewer for their constructive comments, changes and suggestions for improving the overall quality of the manuscript.

Author contributions ANGK conceived the study and designed it with AFM and JD. AFM and JD performed analyses with the help of information provided by all authors. AFM and JD prepared the first draft of the manuscript with contributions, comments and editing from all authors.

Funding Open access funding provided by the Cyprus Libraries Consortium (CLC). The workshops were funded by the UK government through Darwin Plus DPLUS056, DPLUS088 and Darwin Plus Local DPL00014, and updating the Cyprus Database of Alien Species through Darwin Plus DPLUS124. DPLUS175 also helped in providing a forum for exchange of information.

Data availability The study has not generated new data. All records referred to in the text are found in tables in the text or the supplement, with citations provided to sources of information.

Declarations

Conflict of interest The authors have no relevant financial or non-financial competing interests to disclose.

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