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Rapid Communication

Distribution of two invasive alien species of Union concern in Cyprus inland waters

Athina Papatheodoulou[1], Angeliki F. Martinou[2], Panayiotis Klonis[1], Elena Tricarico[3], Niki Chartosia[4], Frances E. Lucy[5] and Margarita Hadjistylli[6,*]

[1]*I.A.CO Environmental and Water Consultant Ltd, Stavrou 3, 2035, Strovolos, Cyprus*

[2]*Joint Services Health Unit, British Forces Cyprus BFPO 57 RAF Akrotiri & The Cyprus Institute, 20 Konstantinou Kavafi str. 2121 Aglantzia, Lefkosia Cyprus*

[3]*Department of Biology, University of Florence, Via Madonna del Piano 6, 50019, Sesto Fiorentino (FI), Italy*

[4]*Department of Biological Sciences, University of Cyprus, 1 Panepistimiou Avenue, 2109, Lefkosia, Cyprus*

[5]*Centre for Environmental Research Innovation and Sustainability (CERIS), Institute of Technology, Sligo, Ash Lane, Sligo, F91 YW50, Ireland*

[6]*Department of Environment, Ministry of Agriculture, Rural Development and Environment, P.O. Box 27658, 2432, Lefkosia, Cyprus*

Author e-mails: *athinap@iaco.com.cy (AP), p.klonis@iaco.com.cy (PK), af.martinou@gmail.com (AFM), elena.tricarico@unifi.it (ET), chartosia.niki@ucy.ac.cy (NC), lucy.frances@itsligo.ie (FEL), xmargarita@gmail.com (MH)*

**Corresponding author*

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Abstract

Spatial baseline distribution information on the presence of the freshwater invasive alien species pond slider *Trachemys scripta* and the red swamp crayfish *Procambarus clarkii*, in Cyprus, is comprehensively reported for the first time. These species have established populations in 44 inland lentic and lotic water bodies, both natural and man-made. The species occur in syntopy in eight locations. *Trachemys scripta* is found in 15 locations, of which only 3 locations do not have established populations. *Procambarus clarkii* is being reported in 30 sites with established populations. This information is a stepping-stone for promoting management measures, for the successful control and/or local eradication of these species in Cyprus.

Key words: red swamp crayfish, pond slider, protected areas, distribution, freshwater non-native species

Introduction

Invasive alien species (IAS) are one of the main drivers of biodiversity change and loss, as the number of alien species arriving in new areas 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; Turbelin et al. 2017) due to their distinct biodiversity and high levels of endemism. While isolation has shaped natural colonization of islands for millions of years, globalization in trade and transport has led to a breakdown of biogeographical barriers and subsequent colonization of islands by alien species. Understanding the risk, distribution and impact of extant IAS on islands is essential for future management of introduction pathways and for targeting possible local eradication of populations that threaten native biodiversity. Likewise, horizon scanning approaches that predict the arrival of new terrestrial, freshwater and marine invasive

species (Roy et al. 2014; Peyton et al. 2019) are management tools that inform both the resource needs to prevent further invasions and the details required for jurisdictional biosecurity regulations. The current study concerns the mapping of the distribution of pond slider *Trachemys scripta* (Thunberg, in Schoepff, 1792) and red swamp crayfish *Procambarus clarkii* (Girard, 1852) on the island of Cyprus. Both species are included in the list of IAS of Union concern (the Union list) (European Commission 2016), the core of EU Regulation 1143/2014, while *T. scripta elegans* is also included in the IUCN list of the top 100 World's worst invaders (GISD 2020). Species included in the Union list are subject to restrictions and measures set out in the Regulation. These restrictions concern the importation, transportation, keeping, selling, breeding, using/exchanging, reproducing/growing and releasing of these species in the environment while EU member states are required to take action on pathways of unintentional introduction, to take measures for the early detection and rapid eradication of these species and to manage species that are already widely spread in their territory (European Union 2014).

The pond slider *T. scripta,* originally from the USA, has been produced in massive numbers in farms for pet trade since the 1970s (Painter and Christman 2000; Vlachogianni et al. 2013). More than 52 million individuals of *T. scripta* were produced for foreign markets between 1989 and 1997 (Telecky 2001). Mostly sold as small hatchlings (3–4 cm carapace length), when they reached adulthood (30 cm carapace length) they were often released by owners in natural systems. The release of these turtles has been reported in Europe (Garcia-Berthou et al. 2007; Teillac-Deschamps et al. 2008; Martins et al. 2018), Africa, South America and Asia (Cadi et al. 2004; Martins et al. 2018; CABI 2020). In comparison to native chelonians in European countries, *T. scripta* exhibits greater reproductive frequency, earlier maturity and greater fecundity, which favours population establishment and competition for food resources and basking sites as well as greater potential for displacing indigenous individuals (Perez-Santigosa et al. 2008; CABI 2020).

Procambarus clarkii is native to parts of Mexico and the USA and has established throughout the world as a result of commercial introductions for harvest as a food source (Souty-Grosset et al. 2016). Invasive populations have been reported from Europe, Asia, Africa, North America, and South America (Foster and Harper 2007; Gonçalves Loureiro et al. 2015; Nunes et al. 2017; Oficialdegui et al. 2019). Impacts include aggressive competition with native freshwater decapods, introduction of the crayfish plague, reduction of macrophyte assemblages, alteration of water quality, predation on and competition with a variety of aquatic species, and negative impacts on bank stability, agricultural and fishing industries (Oscoz et al. 2010; Souty-Grosset et al. 2016; GISD 2020).

Here we report the occurrence of *T. scripta* and *P. clarkii* in the Republic of Cyprus and British Sovereign Bases and we document their distribution

in protected areas. This study is a comprehensive report on the distribution of these two freshwater invasive alien species, completed by the most recent records made by national authorities, professionals and citizens. In addition, the ecological implications on their presence in certain international, EU and national protected areas are discussed.

Materials and methods

The aim of this study was to assess the current distribution of *T. scripta* and *P. clarkii*. Information was collected for the areas under the effective control of the Government of the Republic of Cyprus and the Sovereign Base Areas. Literature review and field surveys were conducted for the collection and synthesis of all available information and the establishment of robust understanding on the distribution of *T. scripta* and *P. clarkii* on the island. The collection of existing information included literature review, screening of available publications and project reports (Stephanou 1987; ICOSTACY 2014; Kouba et al. 2014; Papatheodoulou et al. 2015; I.A.CO 2017, 2018; Tsiamis et al. 2019) as well as personal communication with authorities and stakeholders whose activities involve confirmation of the presence of the species under concern, in both lentic and lotic water bodies. Occurrence data were also integrated with unpublished records personally communicated to the authors and records made by citizens and presented in public websites. This participatory process engaging various interested parties in the form of citizen-science generating scientific data is successfully gaining increasing attention (Perdikaris et al. 2017).

The field surveys were conducted between April and October 2018, in several locations for the investigation/confirmation of the species presence. During that period of the year both species are known to be active (Thomas et al. 1999; Alcorlo et al. 2008).

In order to identify the presence of *P. clarkii*, baited funnel traps were used. Traps consisted of a cylindrical frame net, baited with cat food. The traps were proven successful for the capture of *T. scripta* as well. In addition, 100 m line transects were set up for the confirmation of presence of basking individuals of the pond slider. The baited traps were deployed approximately every 10m along the study areas. The traps were placed 75% submerged in water and tied in the riparian zone. The traps remained on site overnight and were emptied the following day. If no detection occurred the first day, the trapping effort was not repeated. Characteristics for the study locations are given in Supplementary material Table S1. The assessment of population density was beyond the scope of this study and results were simply based on presence or status of establishment (i.e. casual or established). All survey results are shown in Figures 1 and 2, accompanied with specific population status.

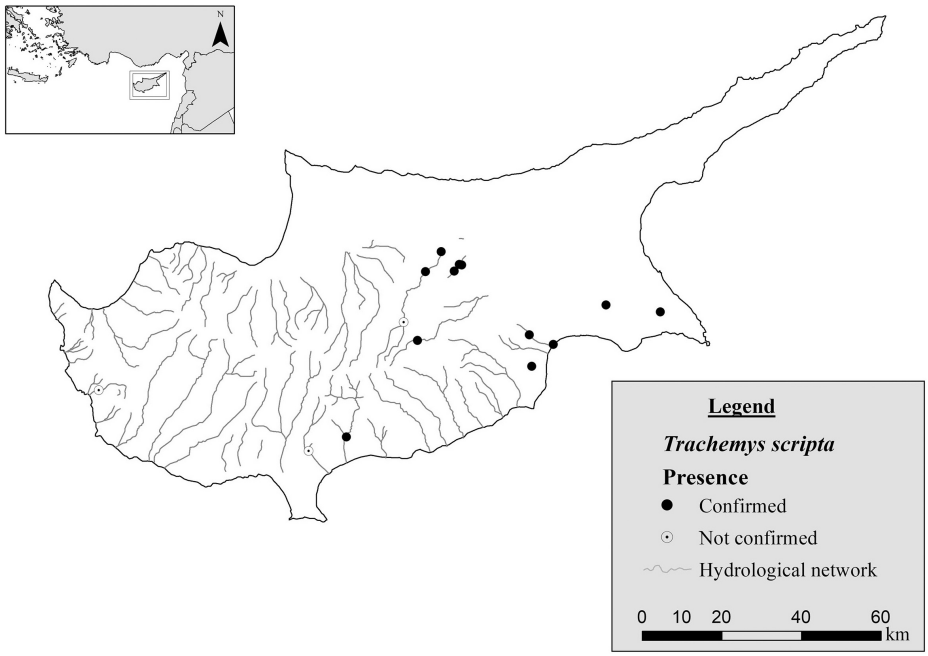

Figure 1. Distribution map of *Trachemys scripta* in Cyprus.

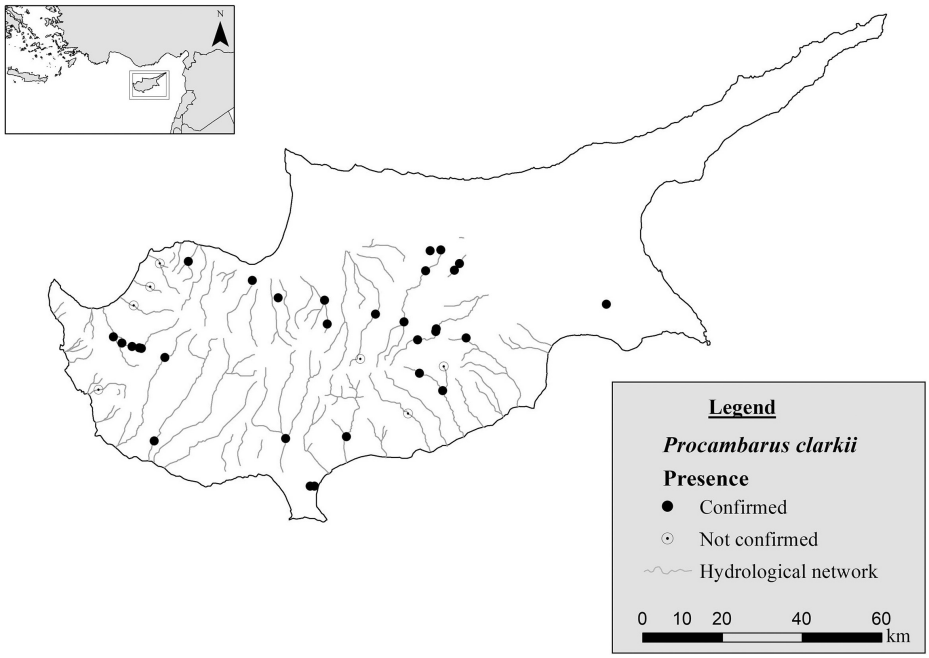

Figure 2. Distribution map of *Procambarus clarkii* in Cyprus.

Results and discussion

Records on the presence of IAS in 44 locations in the island of Cyprus are reported in this publication. *Trachemys scripta* was located in 15 sites of which eight reservoirs, four lakes and three lotic water bodies (Figure 1). In all but three cases, the species has established reproducing populations. At Paralimni lake (Table S1, row 36), Oroklini eastern canal (Table S1, row 34) and Larnaca aqueduct (Table S1, row 23) the presence of the species is casual, with individuals of pet turtles most probably released by their owners. Moreover, in one site, the presence of the species could not be

confirmed by fieldwork even though we had received oral reports on its presence, suggesting either actual absence of the species or low population density, thus non-detection within our sampling scheme. The wide distribution of the species is evident. It might be the case that the species was widespread prior to 2016, when the species was added to the Union List of the IAS Regulation, enforcing a ban on imports and sales throughout Europe, allowing only a year to sell existing stocks, however data on past distribution are insufficient. It is foreseen that, as public gains awareness on the responsible handling of companion animals, illegal releases into the wild will be minimised.

The presence of *P. clarkii* was confirmed in 30 inland freshwater bodies, 21 of which lentic (18 reservoirs and three lakes), eight lotic and in one rainwater overflow pipe, with established populations in each (Figure 2). Twenty-eight of the 30 sites are located within the Republic of Cyprus and two within the Western Sovereign Base Area. The presence of the species could not be confirmed within the current project, in seven additional sites, for which we had received sighting reports. This may be interpreted as, either actual absence of the species or low population density, and non-detectable within our sampling scheme. These sites are also recorded in Figure 2.

The spatial distribution of the species is wider than initially estimated based on existing published information as reported in Table S1. This could be attributed to the insufficient control of stocking in water bodies. There are reports that the species is released into water bodies by individuals for recreational fishing. Such a possibility reveals an active pathway of intentional spread, which requires future management within an integrated management plan. The fact that the crayfish has been recorded in lotic water bodies demonstrates its spread and colonization capabilities. It should also be noted that its presence in the reservoirs or other lentic water bodies often coincides with the presence of its fish predators, like the largemouth bass – *Micropterus salmoides* (Lacepède, 1802) which could potentially exercise control of its population over time. This is the case in more than 70% of the lentic water bodies studied, in which *P. clarkii* co-occurs with predatory fish species (DFMR 2017).

From the 44 locations of detected IAS presence under the current study, the two species occur in syntopy in eight locations (Table S1). The coexistence of the two species reveals an additive pressure of IAS in water bodies. These are likely systems more vulnerable to human interference as they are more accessible to, thus more prone to invasions. This information highlights the importance of prioritizing such sites, both for targeted management applications as well as controls and inspections to minimize illegal release of IAS into the environment.

The majority of the water bodies that host either or both of the species under concern are subject to a protection status of ecological importance (Table S1). Even though the term “protected” covers a wide variety of

designation and different management regimes, within the framework of this study we chose to present sites designated as part of the Birds and Habitats Directives and the national Forest Law 25(I)/2012. These are Special Areas of Conservation (SAC) and Special Protection Area (SPA), designated as part of the Natura 2000 network under the European Directives 92/43/EEC (European Community 1992) and 2009/147/EC (European Union 2009) and the corresponding National Legislations N.153(I)/2003 and N.152(I)/2003, for the areas under the effective control of the Republic of Cyprus and the corresponding Ordinances 26/2007 and 21/2008 of the Sovereign Base Areas. The two Directives are the most important instruments of the European environmental policy, aiming to maintain flora, habitats and fauna at a favourable conservation status. In addition, some of the sites are located within State Forests or National Forest Parks and three locations are within wetlands designated as wetland of international importance under the Ramsar Convention. These protection statuses are related to the preservation, protection or improvement of the quality of the environment, which include provisions that address the risks of introduced species to native biodiversity. Twenty-three of the water bodies, in which the two species of concern have been recorded, are either SAC or SPA or both SAC and SPA, eight lentic water bodies are within State Forests, two within National Forest Parks and three water bodies within Ramsar sites (Table S1). *Procambarus clarkii* has been recorded in 27 protected areas, whereas *T. scripta* has been recorded in seven. The impacts of these invasive species on protected or red-listed species has not been assessed, and requires future thorough research to identify both the level of threat and impact as well as the measures that need to be taken to minimize this impact.

Although the establishment of protected areas aims to safeguard biodiversity from potential threats, reports on increasing impacts of IAS to native species and ecosystem structure suggest that biological invasions may decrease the conservation potential of protected areas (Monaco and Genovesi 2014; Rico-Sánchez et al. 2020). The impact of IAS on the protected species or habitat is not always direct. IAS could exert indirect, cumulative or induced impact by their presence or lateral interactions. This is even truer for islands. Islands have an inherent vulnerability to IAS, due to their isolation. Thus, there is a need of tailored measures for combating IAS negative impacts (Scalera and Zaghi 2004; Spatz et al. 2017). This cannot be emphasised enough, as the application of island-wide effective control at crossing points is not in full operation in the case of Cyprus, due to the political conditions. The impact of biological invasions can even be worse in protected areas than elsewhere, because these areas preserve key elements of biological diversity (Monaco and Genovesi 2014).

Originating from America, *P. clarkii* was introduced intentionally in the 1980's in three lentic water bodies in Cyprus for angling purposes. A FAO

Country Report for 1986–1987 stated that the species was flourishing in the Athalassa dam and it was introduced in two other dams (Stephanou 1987). Since its introduction, it subsequently spread successfully in the island. Its distribution in Cyprus is wider than the pond slider, attributed mainly to its plasticity, reproductive potential, characterised by high fecundity, multiple energy investment strategies and flexibility in the timing of life history events (Garcia-Berthou et al. 2007; Alcorlo et al. 2008). Moreover, it is estimated that the number of individuals released in the wild, as well as the number of repeated introductions/releases and the independent sites of releasing throughout their invasion history across the island, has been greater than those of *T. scripta*. Even though *T. scripta* is not an explosive species capable of rapid colonisation of feral habitats, it has a competitive advantage towards other chelonians, as it reaches maturity comparatively earlier, and has greater fecundity thus outnumbering them in optimal environments (Cadi et al. 2004; Perez-Santigosa et al. 2008).

There are studies showing competitive behaviours of both species towards native representatives of the same groups. Savvides et al. (2015) showed, under laboratory conditions in Cyprus, that the crayfish exhibited more successful competitive behaviour in securing shelters than the indigenous to the island and protected freshwater crab *Potamon potamios* (Olivier, 1804), indicating that in the wild the invader could displace or exclude the native crab from sites utilised for reproduction and predator avoidance. Though studies are needed to evaluate the interactions between the two species in nature, *P. potamios* has been recorded to co-exist with *P. clarkii* in lotic water bodies of Pafos district, in all three sites of Stavros tis Psokas river (Table S1, rows 44–46). *Potamon potamios* is the only freshwater crab species present on the island. The area of occurrence is designated as a SPA (Table S1). In Spain, *T. scripta* was found to affect the survival of indigenous species, competing for basking sites and displacing individuals of other species (Perez-Santigosa et al. 2008). In Cyprus *T. scripta* has in some lentic water bodies sympatric populations with the only autochthonous freshwater turtle *Mauremys rivulata* (Valenciennes, 1833), which is an Annex II species of the Habitats Directive 92/43/EEC. Both species have been reported to reproduce successfully in lentic waters. This occurs in Athalassa reservoir and Agios Georgios lake (Table S1, rows 10 and 5 respectively). In these water bodies, the population density of the pond slider is probably the largest in the wild in Cyprus, most likely because these water bodies are within the capital (Lefkosia) city and close to inhabited areas which are easily accessible by the public to use, albeit illegally, for releasing those sliders kept as pets. Both *T. scripta* and *M. rivulata* co-exist and reproduce successfully. The intensity of any competitive relationships between *T. scripta* and *M. rivulata* or *P. potamios* and *P. clarkii*, cannot be assessed using the existing data, and no conclusive remarks can be yielded on their relations without further targeted studies. Considering the

significance of indigenous species as well as the risks posed by IAS in terms of competition and/or pathogens, understanding the distribution patterns of IAS is of fundamental importance.

Conclusions

In the present study, a comprehensive and updated picture of the current distribution of *T. scripta* and *P. clarkii* in Cyprus has been provided. Detailed information of relative abundance and population dynamics are needed and related work is ongoing. Even though the negative effects of these species on the aquatic diversity of lentic and lotic water bodies are known, understanding their ecological interactions and the disturbance factor exerted to the native fauna sharing similar niches is a prerequisite prior to the application of any control measures.

An aspect of equal importance and integral part of any management program is the general public awareness on the problem and active participation of citizens in minimizing the spread of IAS or contributing to their management by sharing relevant information with the competent authorities. Recent contacts of *T. scripta* (and other turtle) owners with the national competent authority inquiring about ways to safely remove their pet from their homes indicate that the public has started becoming more aware and sensitive with regards to handling invasive pets. The case of *P. clarkii* is more complicated since it is not a species commonly held by people in home aquaria in Cyprus, and its spread is mostly linked to uncontrolled releases in water bodies for recreational fishing. Thus, in such cases a more targeted raising awareness campaign with anglers and amateur fishermen will be more effective in addressing the problem. In both cases, ongoing efforts in Cyprus, through projects and collaborations among competent authorities, stakeholders and NGOs, aiming to make people aware of the risks associated with IAS and urging them to report sightings of individuals of the two species in water bodies, will help reduce their spread and facilitate their management.

The efficacy of any strategy to address IAS depends on the available information, and on the sharing of data, knowledge and experience. Similar inventories of IAS are an essential management tool for competent authorities in efforts to prevent and control biological invasions. Features such as riverscapes, that provide areas for colonization, facilitating the spread of freshwater IAS, should also be mapped and monitored (Treguier et al. 2011; Bolch et al. 2020). Furthermore, the effective management of IAS requires good quality data on the spread of invasive species, as well as access to information on the biological traits of the species, their impacts, and on the available management alternatives. Data collected during the current study will be used for updating the information and distribution on the online Cyprus Database of Alien Species (CYDAS) (Martinou et al. 2020) for *T. scripta* and *P. clarkii* and can be used for informing the options for management of these species in Cyprus.

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Authors' Contribution

PA was involved in sample design and methodology, investigation and data collection, data analysis and interpretation, writing the original draft, reviewing and editing; MA was involved in investigation and data collection, writing the original draft, reviewing and editing; KP was involved in investigation and data collection, reviewing and editing the manuscript; TE was involved in sample design and methodology, data collection, reviewing and editing the manuscript; CN was involved in data collection, reviewing and editing the manuscript; LFE was involved in reviewing and editing the manuscript; HM was involved in conceptualizing the research idea, sample design and methodology and reviewing and editing the manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Records of *Trachemys scripta* and *Procambarus clarkii* in Cyprus.

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