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Alien-Invasive Marine Species in Warmer Conditions of a Mediterranean Region (Fethiye-Göcek SEPA, Muğla, Türkiye)

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ABSTRACT

This paper reveals information and describes an updated review on eight non-indigenous marine species (NIS) detected in Fethiye-Göcek SEPA (Muğla, Türkiye). *Cheilodipterus novemstriatus* is observed with *Diadema setosum* that has been detected in large communities grazing intensively on algal canopies. In some sites, *Synaptula reciprocans*, *Pterois miles* and *Torquigener flavimaculosus*, mainly along the South Aegean and Mediterranean coasts, are recorded. *Ganonema farinosum* and *Caulerpa taxifolia* var. *distichophylla* and *C. racemosa* f. *requienii* with a significant spread towards the northern Aegean Sea, are documentated. Except for *C. taxifolia* var. *distichophylla*, the main vector of these bioinvasions, is the corridor (Suez Canal) and their origin is the Red Sea. Regarded as a main threat to the coastal biodiversity in the Mediterranean, NIS have been one of the main indicators of ecological status in accordance with the EU Marine Strategy Framework Directive, 2017. Therefore, constructing regional datasets from the Turkish coasts, the current work will contribute to the implementations of MSFD, 2017 for the regulatory, conservative and management purposes.

KEYWORDS: Non-indigenous species (NIS), bioinvasion, Eastern Mediterranean, climate change

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1. Introduction

As well as being considered as a biodiversity hotspot, the semi-enclosed Mediterranean Sea, is also one of the well-known hotspots of bioinvasion and it is distinguished by a high proportion of endemic species (Rilov and Galil, 2009; Zenetos et al., 2009; Coll et al., 2010; Fraschetti et al., 2011; Çınar, 2013). Mediterranean coasts are subjected to several threats, such as human pressures; overfishing, anchoring, recreational activities, and pollution. Furthermore, rapid water temperature increase in the late 1990s, and sea level rising, have been accompanied by dramatic substitutions in the Mediterranean communities. Accordingly, driven by climate change, the introduction of non-indigenous species (NIS), have triggered regional mass mortalities, therefore, significant habitat shifts (Giakoumi et al., 2015), and tropicalization in native ecosystems of the Mediterranean Sea (Bianchi and Morri, 2003; Galanidi et al., 2018; Bianchi et al., 2018; Albano et al., 2021; Garrabou et al., 2022).

In the recent years, NIS have been a main challenge between the scientists and policy makers due to their critical consequences on coastal ecosystems with a high conservation value (Seebens et al., 2017, Katsanevakis et al., 2018; 2020; Tsirintanis et al., 2022), and they have dominated the Mediterranean coasts through the Gibraltar Strait or the Suez Canal (Zenetos et al., 2017). Located on the eastern part of the Mediterranean Sea, Türkiye is considerably impacted by bioinvasions owing to the suitable environmental conditions for the NIS. They are able to adapt to the fluctuations in the physico-chemical parameters (temperature, pH, salinity, nutrients, etc.) of sea water (Zenetos et al., 2011). NIS are introduced into the Turkish coasts of the Mediterranean Sea mainly from the Indo-Pacific (20%) and the Atlantic Ocean (10%) via shipping activities, fouling, ballast waters, aquaculture industry and the Suez Canal (Galil et al., 2015; Çınar et al., 2021). Most of the alien species from the Red Sea are Indo-Pacific originated (58%) according to the close connection between the Suez Canal and the Levantine Sea, where they easily spread with an increasing trend towards the northern Aegean Sea and the Black Sea through the prevailing currents and shipping activities (Sini et al., 2017; Güreşen et al., 2015).

Previously, the marine alien taxa recorded from the Turkish coasts, have been reported by national experts (Çınar et al., 2005; 2006; 2011; 2021; Taşkın et al., 2011; 2021). According to the latest studies, approximately 65% of the total number of alien and invasive species introduced to the Mediterranean Sea, are revealed from the Turkish coasts. 413 species of marine alien taxa reported from the coasts of the Levantine Sea; whereas 28 species are reported from the Black Sea coasts. Considering the taxonomic groups having invasive features, Mollusca is dominant among other groups in terms of the species number (123 species), subsequently, Foraminifera (91 species), Fish (80 species), Arthropoda (79 species) and Rhodophyta, Phaeophyceae, Chlorophyta and Magnoliophyta (47 species), have been reported on the Turkish coasts (Taşkın et al., 2011; Çınar et al., 2021).

Consequently, bioinvasions recently regarded as a main threat to the coastal biodiversity, have been one of the main indicators of ecological status in accordance with the European Union Marine Strategy Framework Directive (MSFD, 2017) (Zenetos et al., 2022; 2012; Zenetos and Galanidi, 2020; Kleitou et al., 2025). Therefore, the present paper is aimed to describe an updated review of the eight alien and invasive

marine species recorded in the Special Environmental Protected Area (SEPA) of Fethiye-Göcek (Muğla, Türkiye) by 2024. We provide detailed information on status and extension of marine alien taxa, as well as the main vectors of their introduction to the Mediterranean Sea.

Policy implementations on bioinvasions, have initiated the monitoring applications in order to investigate and decrease the impacts of NIS (Tsiamis et al., 2019; 2020; Zenetos and Galanidi, 2020; EC, 2020). Constructing regional datasets of marine alien taxa with invasive features from the Turkish coasts, the current work will also contribute to the accomplishment of the MSFD, 2017 for the regulatory, conservative and management purposes.

2. Material and Methods

Sampling and observations are conducted by SCUBA diving in Fethiye-Göcek SEPA (Muğla, Türkiye) (36°39'39" N, 29°03'14" E) between May 2024 – 2025, from the shore up to a depth of 40 m. The photographic samplings were taken by under water video camera (Olympus OMD E-M5). Research area and sampling sites (1: Kızılada, 2: Katrancık Isle, 3: Göcek Isle, 4: Tersane Isle, 5: Darboğaz, 6: Kille) in Fethiye-Göcek SEPA (Muğla, Türkiye) are given in Figure 1.

Figure 1. Research area and sampling stations (1: Kızılada, 2: Katrancık Isle, 3: Göcek Isle, 4: Tersane Isle, 5: Darboğaz, 6: Kille) in Fethiye-Göcek SEPA (Fethiye, Muğla, Türkiye).

3. Results and Discussion

Eight alien and invasive marine species are recorded along Fethiye-Göcek SEPA; *Cheilodipterus novemstriatus* (Indian Ocean twospot cardinal fish) is observed with herbivorous *Diadema setosum* (long-spined urchin) that has been detected in large communities grazing intensively on algal canopies. In some sites, *Synaptula reciprocans* (worm sea cucumber) (Figure 3b), *Pterois miles* (lion fish) (Figure 4a), and *Torquigener flavimaculosus* (yellow spotted puffer fish) (Figure 4b) are recorded.

Alien-invasive red alga *Ganonema farinosum* and two green algae (*Caulerpa taxifolia* var. *distichophylla* and *C. racemosa* f. *requienii*), are documentated (Figures 2a,b,c). There has been a significant spread of *Caulerpa taxifolia* (M. Vahl) C. Agardh recognized with invasive characteristics. Except for *Caulerpa taxifolia* var. *distichophylla*, reported from the Marmara Sea (Taşkın et al., 2023), the main vector of other species is the corridor (Suez Canal) and their origin is the Red Sea (Table 1). Besides, Caulerpales increase the trend of their abundance towards the northern Aegean Sea, the red alga *Ganonema farinosum* has extended its distribution towards the Black Sea, while other species maintain their distribution mainly along the South Aegean and Mediterranean coasts.

Considering their habitat distribution, *G. farinosum* is most abundant on shallow rocky coasts, while *C. taxifolia* var. *distichophylla* and *C. racemosa* f. *requienii*, are found at lower depths where *Posidonia oceanica* meadows retreat. As for, *D. setosum* thrives on coastal rocks, while *S. reciprocans* is found in *P. oceanica* meadows and on sponges. Subsequently, *T. flavimaculosus* is densely distributed at all stations and two individuals of *P. miles* were found at Kızılada Isle and three individuals at Darboğaz Site.

Table 1. Invasive alien species recorded in the research area.

Taxon (Phylum)	Site	Main vector of introduced species/origin	Distribution on Turkish coasts
Ganonema farinosum (Lamouroux) Fan & Wang (Rhodophyta)	Kızılada Isle, Katrancık Isle	Suez Canal/Red Sea	Black Sea, Marmara Sea, Aegean Sea, Mediterranean Sea
Caulerpa racemosa f. *requienii* (Montagne) Weber Bosse (Chlorophyta)	Katrancık Isle, Kille, Darboğaz	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea
Caulerpa taxifolia var. d*istichophylla* (Sonder) Verlaque, Huisman&Procacin (Chlorophyta)	Katrancık Isle,	Shipping/Pacific Ocean	Marmara Sea, Aegean Sea, Mediterranean Sea
Diadema setosum (Leske, 1778) (Echinodermata)	Kızılada Isle, Kille, Darboğaz, Tersane Isle	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea
Synaptula reciprocans (Forrskål, 1775) (Echinodermata)	Kızılada Isle, Kille, Darboğaz, Tersane Isle	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea

Cheilodipterus novemstriatus (Rüppell, 1838) (Pisces)	Göcek Isle, Kızılada Isle	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea
Pterois miles (Bennett, 1828) (Pisces)	Kızılada Isle, Darboğaz	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea
Torquigener flavimaculosus Hardy & Randall, 1983 (Pisces)	Kızılada Isle, Kille, Darboğaz, Tersane Isle, Katrancık Isle Göcek Isle	Suez Canal/Red Sea	Aegean Sea, Mediterranean Sea

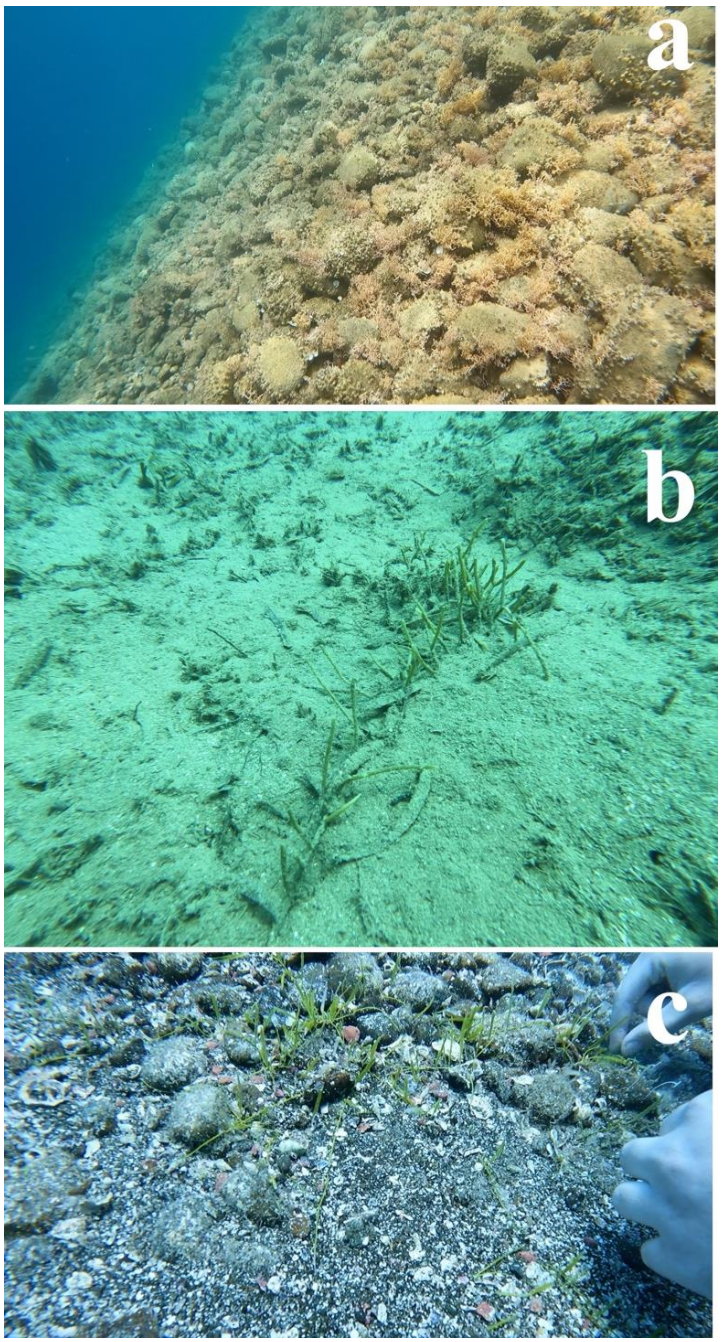

Figure 2. Alien and invasive marine macroalgae (**a:** *Ganonema farinosum*, **b:** *Caulerpa racemosa* f. *requienii*, **c:** *Caulerpa taxifolia* var. *distichophylla*) in research area.

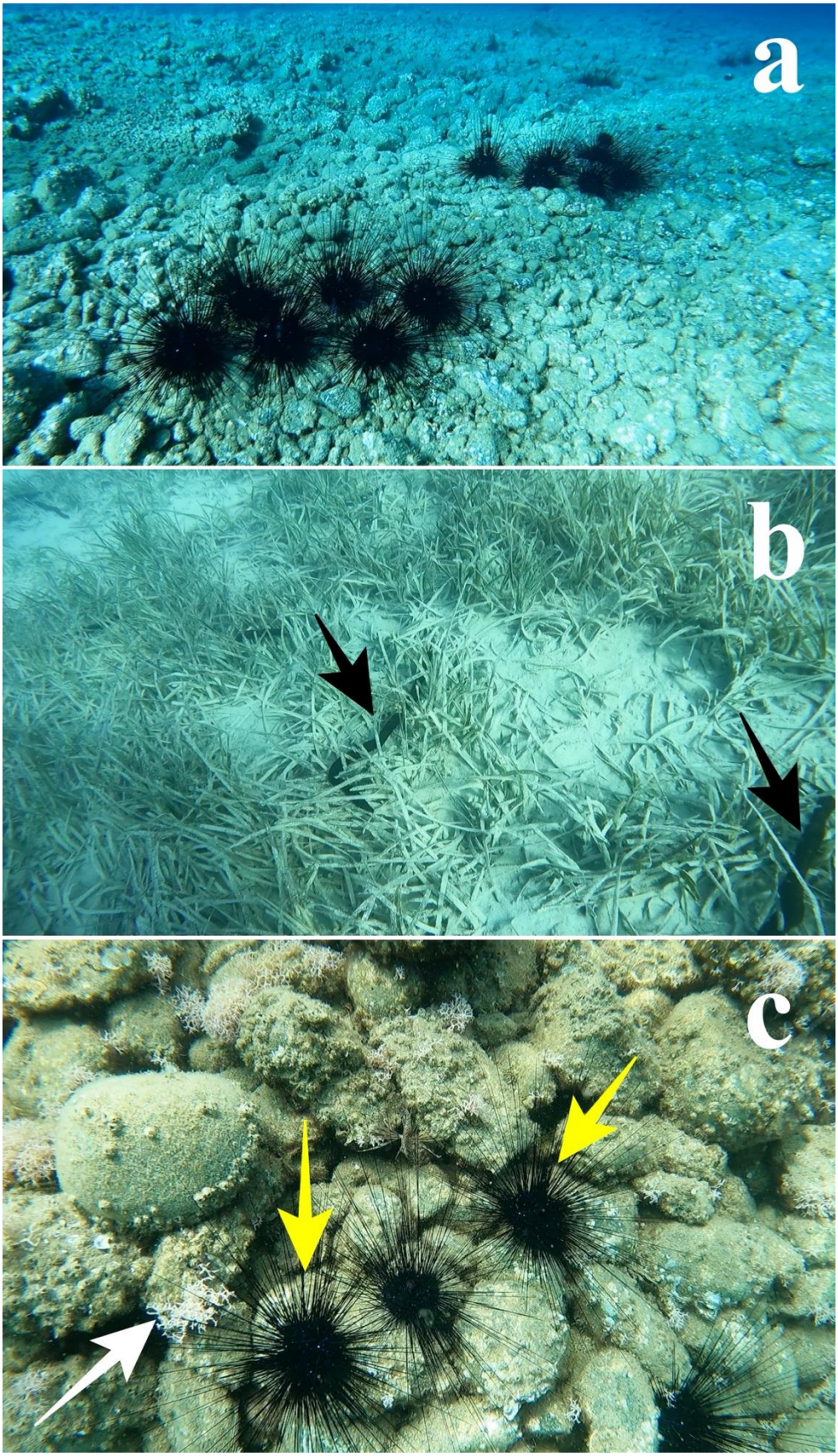

Figure 3. Alien and invasive marine species (**a:** *Diadema setosum*, **b:** *Synaptula reciprocans*, **c:** *Diadema setosum*, yellow arrows; *Ganonema farinosum*, white arrow) in research area.

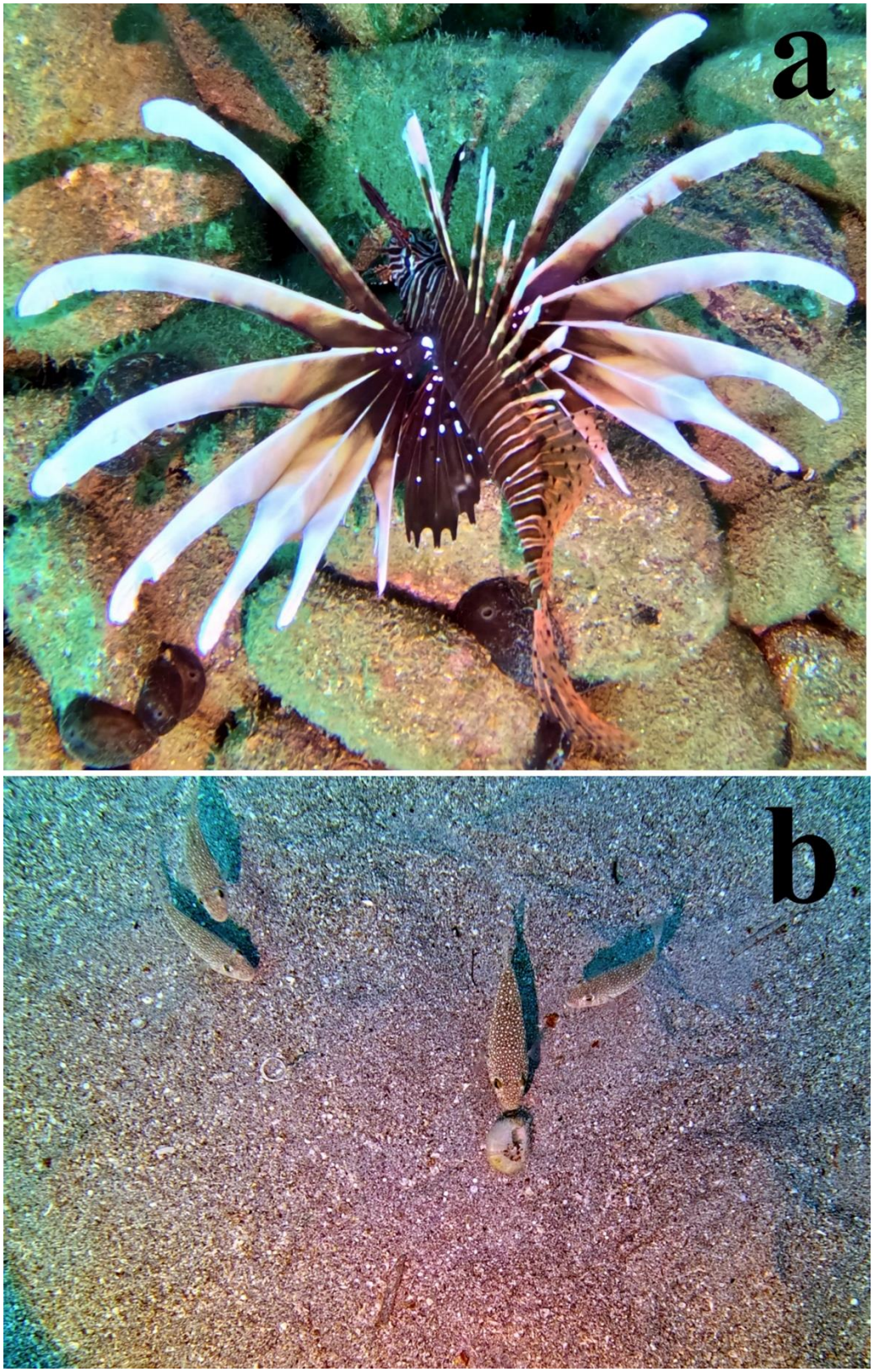

Figure 4. Alien and invasive marine species (**a:** *Pterois miles*, **b:** *Torquigener flavimaculosus*) in research area.

4. Conclusion

Recent studies have shown an increase in the number of alien-invasive species along the Mediterranean and Aegean coasts of Türkiye, and particularly in some sites in our study region, these species have become dominant in the ecosystem. Rising sea temperatures due to climate change and global warming are predicted to trigger tropicalization, particularly in the Levanten Sea (Eastern Mediterranean), and expand the range of alien-invasive species.

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Compliance with Ethical Standards

Conflict of interest
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Ethical approval
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