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MARINE RECORD

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A lionfish (*Pterois miles*) invasion has begun in the Mediterranean Sea

Demetris Kletou^{1,2*}, Jason M. Hall-Spencer^{1,3} and Periklis Kleitou²

Abstract

Until now, few sightings of the alien lionfish *Pterois miles* have been reported in the Mediterranean and it was questionable whether the species could invade this region like it has in the western Atlantic. Here, we present evidence from divers and fishermen that lionfish have recently increased in abundance and within a year colonised almost the entire south eastern coast of Cyprus, likely due to sea surface warming. At least 23 different fish are reported of which 6 were removed. Groups of lionfish exhibiting mating behaviour have been noted for the first time in the Mediterranean. Managers need this information and should alert stakeholders to the potential ecological and socio-economic impacts that may arise from a lionfish invasion. Actions could involve incentives to engage divers and fishermen in lionfish removal programmes, as these have worked well at shallow depths in the Caribbean. Given that the Suez Canal has recently been widened and deepened, measures will need to be put in place to help prevent further invasion.

Keywords: Lionfish, *Pterois miles*, Biological invasion, Non-indigenous, Alien species, Mediterranean Sea

Introduction

The Mediterranean Sea represents around 0.82 % area and 0.3 % volume of the world ocean but it contains 4–18 % of described marine organisms and is a biodiversity hotspot with estimated 17,000 species (Coll et al. 2010). Mediterranean ecosystems face multiple anthropogenic threats such as climate change, over fishing and alien invasions (Kletou & Hall-Spencer 2012). Mediterranean seawater temperatures are steadily increasing, and alien species are spreading, causing community shifts and tropicalization (Lejeune et al. 2010; Montefalcone et al. 2015). There are now >1000 alien species in the Mediterranean and the majority are thermophilic species that have entered the eastern basin through the Suez Canal (Katsanevakis et al. 2014). Recent enlargement of this canal coupled with sea surface warming is raising concerns that this problem will get worse (Galil et al. 2015).

Lessepsian fish invasion rates are now increasing rapidly; ca 40 % of the 130 alien fish species now living in the Mediterranean have been reported since

2001 and these have expanded their geographical range during this time (Zenetos et al. 2012). The bluespotted cornetfish *Fistularia commersonii* colonised almost the entire Mediterranean in just 7 years (Azzurro et al. 2012) where it now poses a threat to local ecosystems since it feeds on a large variety of prey (41 taxa) and specialises on juveniles of the commercial fish *Boops boops* and *Spicara smaris* (Bariche et al. 2009). The pufferfish *Lagocephalus sceleratus* has now reached the central Mediterranean (Azzurro et al. 2014) and is expanding west (Souissi et al. 2014). It eats economically important cephalopods *Sepia officinalis* and *Octopus vulgaris* (Cuvier 1797) and is classed as a fisheries pest (Kalogirou 2013). Some countries have initiated invasive fish eradication programmes, for example the Cypriot authorities have been compensating fishermen for their pufferfish catches during the reproductive season, resulting in massive removals of pufferfish biomass from the eastern Mediterranean (Rousou et al. 2014).

Few worldwide fish invasions of similar magnitude are documented; the introduction of the red lionfish *Pterois volitans* and the devil firefish *P. miles* in the western Atlantic is one of the fastest and most ecologically harmful marine fish introductions to date (Albins & Hixon 2013). In their native range, *P. miles*

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occur in the Indian Ocean from South Africa to the Red Sea and Persian Gulf, and east to Sumatra while *P. volitans* are observed in both the western and central Pacific and western Australia. *Pterois volitans* looks similar to *P. miles* but has an additional dorsal fin ray and an extra anal fin ray (Schultz 1986). A decade after either intentional or accidental aquarium release in Florida, *P. volitans* became fully established throughout the southeast United States and the Caribbean Sea, extending to South America and much of the Gulf of Mexico (Schofield et al. 2015). The alien lionfish population has low genetic diversity and is thought to originate from a small founder population in the southeast United States (Betancur-R et al. 2011). The lionfish are generalist carnivores and can feed on a large variety of fish and crustaceans although large individuals prey almost exclusively on fish (Côté et al. 2013b). Lionfish spawn every 4 days year-round, producing around two million buoyant gelatinous eggs per year (Morris et al. 2009). Their eggs are planktonic and can ride the ocean currents and cover large distances for about a month before they settle (Ahrenholz & Morris 2010). In western Atlantic, lionfish are more abundant than in their native region and have become the dominant predator on coral reefs with a great impact on native reef fishes, decreasing the abundance of >40 prey species by 65 % on average, in just 2 years (Green et al. 2012). Their dramatic invasive success results from a combination of factors such as early maturation and reproduction, anti-predatory venomous defences and ecological versatility of the lionfish coupled with naïve prey and the overfishing of native predators (Côté et al. 2013a).

In the Mediterranean Sea, one *P. miles* was recorded in 1991 off Israel (Golani & Sonin 1992). After two decades of silence, two specimens were captured off the coast of Lebanon in 2012 (Bariche et al. 2013). Soon after, two more were reported in a newspaper article, captured off Cyprus and in 2014, another specimen was sighted in Turkey, then in 2015 two more were captured in Cyprus and then sighted in Rhodes in Greece (Turan et al. 2014; Oray et al. 2015; Crocetta et al. 2015; Iglésias & Frotté 2015). Recently, several records were reported from south Turkey indicating a westerly migration of the species towards the Aegean Sea (Turan & Öztürk 2015). Hitherto, lionfish were reported only occasionally in the eastern Mediterranean Sea and their successful invasion in the Mediterranean Sea is questionable due to unfavourable oceanographic conditions that limit the wide dispersion of lionfish larvae (Johnston & Purkis 2014).

In this article, we present evidence that the threat of lionfish invasion in the eastern Mediterranean Sea is real and is probably underway. Sightings of the lionfish *P. miles* from the coastal waters of south Cyprus are becoming more frequent in contrast to recent model

predictions (Poursanidis 2015). Furthermore, groups of lionfish have been sighted together for the first time in the Mediterranean.

Materials and methods

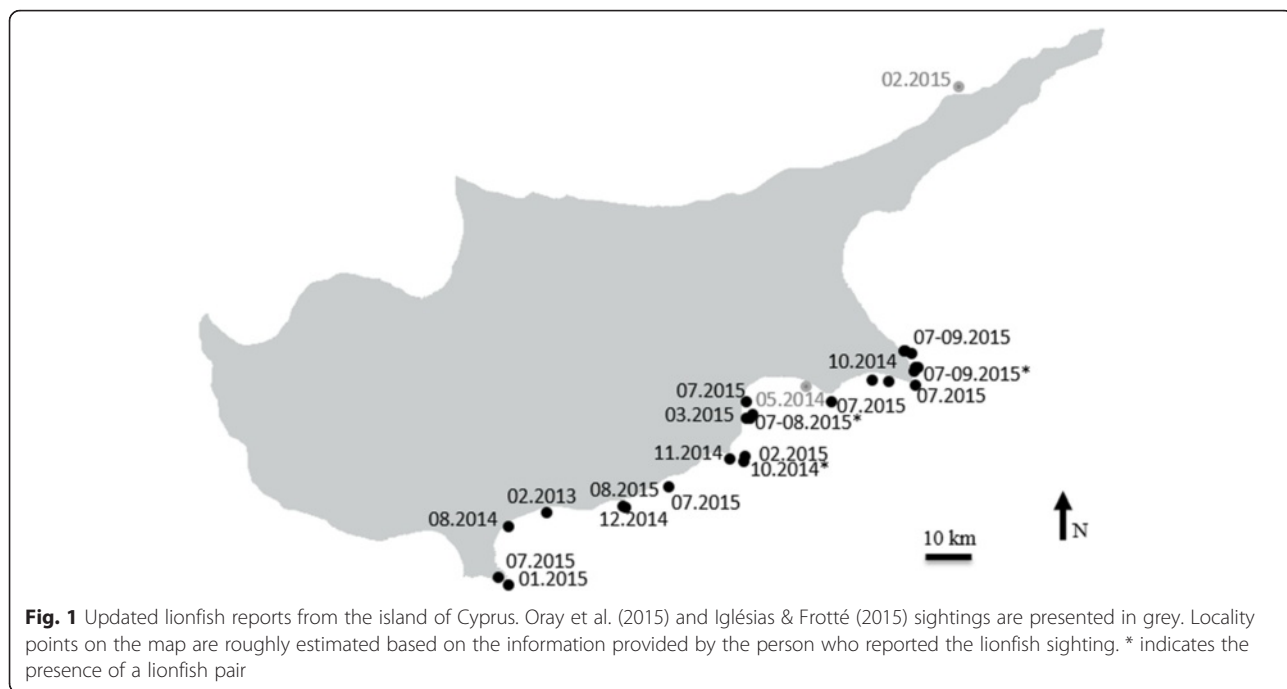
In 2015 reports of lionfish sightings on electronic social media/networks and within the local community of divers and fishermen became more frequent. To map lionfish distribution around Cyprus, we collated information from local divers and spearfishermen who reported lionfish encounters in the coastal waters. In-person and telephone interviews were conducted. Interviewees with proof of lionfish sightings willingly provided the evidence (photographs and/or videos) for the purposes of this study. Date of sighting, locality (area and depth) and other information were recorded for validated lionfish sightings. In addition, governmental officers of the Department of Fisheries and Marine Research (DFMR) of the Ministry of Agriculture, Rural Development and Environment shared information and specimens captured in trammel nets by local coastal fishermen.

Results

The lionfish *P. miles* has spread rapidly and colonised almost the entire south eastern coast of Cyprus, from Limassol (south) to Protaras (south east) in just 1 year (Fig. 1). Divers and government officers that were questioned in this study mentioned >10 additional lionfish sightings and captures that were unfortunately not photographed so are not included in our database.

Officers from DFMR provided four specimens for the purposes of this study. One is now alive in an aquarium at DFMR offices and another is among the first two undocumented reports made from Cyprus back in February 2013 (Bariche et al. 2013). More details about these specimens are presented in Fig. 2. Most validated reports of lionfish come from scuba divers and freedivers across south Cyprus. Here we list 24 new sightings of at least 19 different fish (Fig. 3, Table 1).

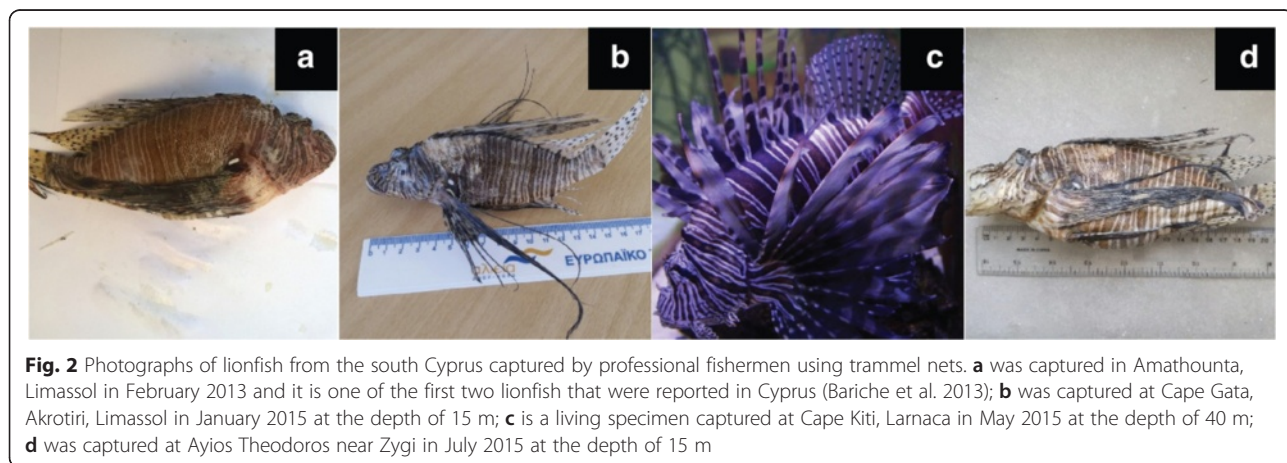
Three pairs of lionfish have been photographed, one at Zenobia wreck at 20 m depth, another near Cape Kiti at 42–43 m (Photo D, Fig. 3) and one more at Cyclops caves near Cape Greco at 12–15 m depth. The Cyclops pair has been photographed many times by different recreational scuba divers both as singletons or together (Photos C, I, J, O, Q, W and X, Fig. 3). The distinctive stripe pattern of these two individuals allows their identification through photos and the tracking of their movement. They were documented together at the same rock formation for a period of 2 months between July and September 2015 (Photos O, Q, W and X, Fig. 3). It is noteworthy that one individual from the pair named β with a unique stripe pattern on its left side, may have been reported on the other side of Cape Greco, around 10 km



from Cyclops caves, several months earlier in October 2014 (Photo C, Fig. 3). The other individual, named α , has very distinctive stripes on its right side and was first sighted at Cyclops caves on 7 of July 2015 and the next day it was reported towards Green bay, about 2 km to the north east (Photos I and J, Fig. 3). Two weeks later it was found back at Cyclops caves with β where they remained together for at least 2 months. About a week before the pairing was sighted at Cyclops caves, a third lionfish was reported at the site but it was not sighted again thereafter (Photo L, Fig. 3). Recently, a different lionfish has joined the pair (Photo X, Fig. 3).

Discussion

The possibility of a lionfish invasion in the Mediterranean Sea and the potential ecological and socio-economic impacts that may follow have been largely neglected by the regional scientific community, managers and other stakeholders. Few validated reports of lionfish sightings exist from the region, which creates muted concern and uncertainty about the ability of the species to colonise the Mediterranean. Furthermore, model simulations have suggested that this would be unlikely to happen (Johnston & Purkis 2014) although the warming and acidification of Mediterranean waters due to CO₂ emissions may require



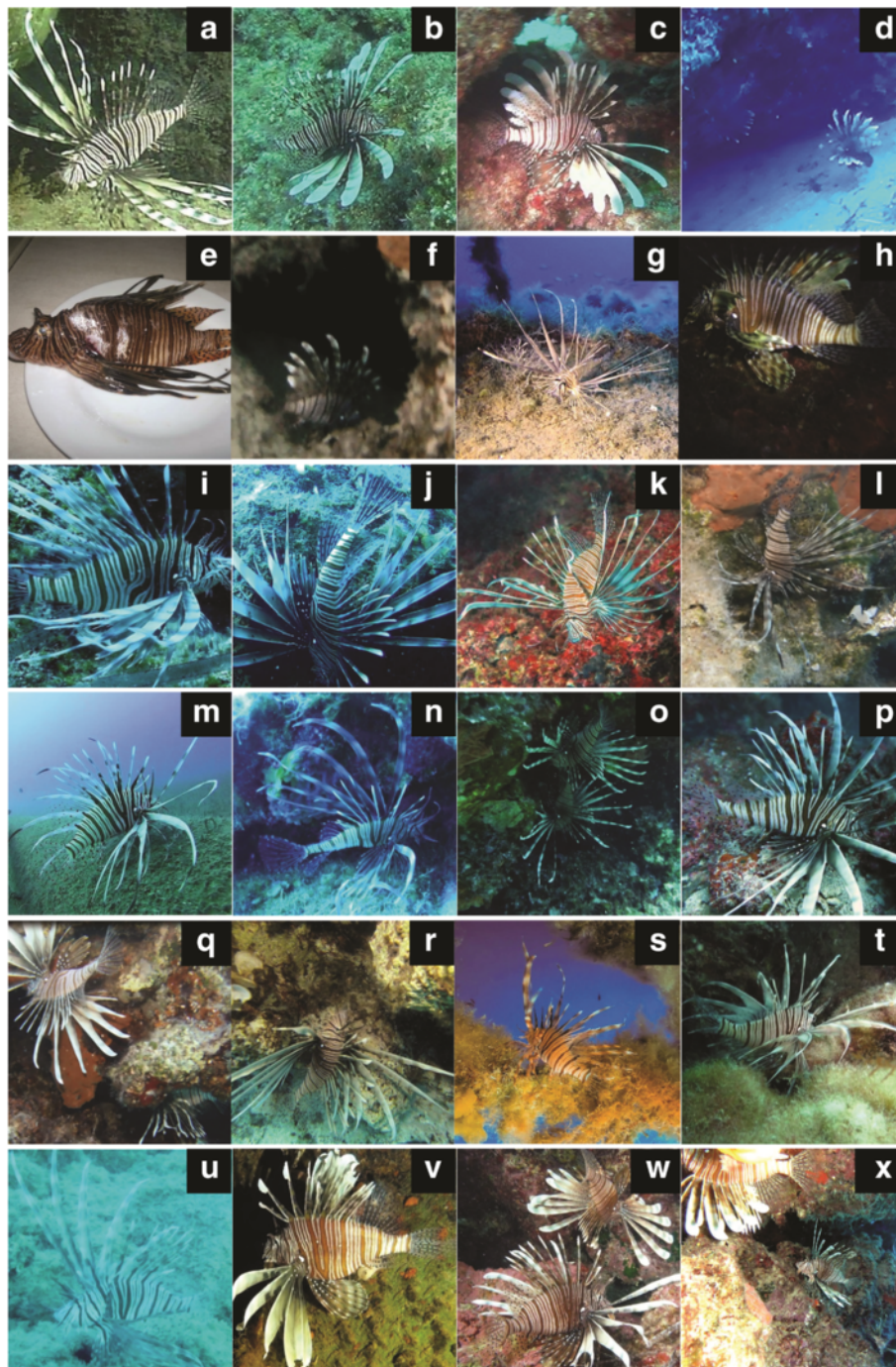


Fig. 3 Photographs of lionfish from the south coast of Cyprus captured by recreational scuba divers, free-divers or spear-fishermen. Further details on Table 1

new modelling approaches (Hall-Spencer & Allen 2015). The lionfish first appeared in the eastern Mediterranean at about the same time that they were first reported off Florida. There they spread rapidly and colonised almost all warm parts of the east coast of United States, the Gulf of Mexico and the entire Caribbean Sea (Schofield et al.

2015) whereas more than two decades passed for a second sighting to occur in the Mediterranean Sea.

Here, we present >20 lionfish sightings (mostly by divers) from the coastal waters of south Cyprus during over the past year, providing evidence that the lionfish invasion in the Mediterranean Sea is becoming a clear threat that

Table 1 Lionfish sightings details from divers who took the photographs in Fig. 3. Coordinates are best available estimates

Photo	Date	Recorded by	Method of detection	Site	Depth (m)	Type of substrate	Latitude (N)	Longitude (E)
A	28.08.2014	Stathis Georgiou	Freediving/ Spearfishing	Limassol Marina (external side of wave breakers)	15	Artificial hard	34°39.9'	33°2.4'
B	08.10.2014	Tasos Charalambous	Freediving/ Spearfishing	Near Ayia Napa port, Famagusta	09–10	Natural hard	34°58.8'	34°0.3'
C	15.10.2014	Tasos Charalambous	Freediving/ Spearfishing	2 km from Ayia Napa port towards Cape Greco, Famagusta	10–11	Natural hard	34°58.4'	34°1.8'
D	25.10.2014	George Vasiliou	Freediving/ Spearfishing	Cape Kiti, Larnaca	42–43	Natural hard	34°49.6'	33°38.4'
E	23.11.2014	Constantinos Afxentiou	Freediving/ Spearfishing	Cape Kiti, Larnaca	10	Natural hard	34°48.7'	33°36.3'
F	20.12.2014	Giannis Ioannou	Freediving/ Spearfishing	Vasiliko Port (external side of wave breakers), Larnaca	5	Artificial hard	34°42.9'	33°19.0'
G	28.03.2015	Andreas Makris	Recreational scuba diving	Alexandria Wreck, Larnaca	30	Wreck	34°53.6'	33°39.2'
H	05.07.2015	George Pavlides	Freediving/ Spearfishing	Akrotiri, Limassol	13	Natural hard	34°33.0'	33°1.0'
I	07.07.2015	Vagelis Gavalas	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	13	Natural hard	34°59.1'	34°4.6'
J	08.07.2015	Wolf Werner	Recreational scuba diving	Green Bay, Protaras, Famagusta	12	Natural hard	35°0.1'	34°4.1'
K	10.07.2015	Maria Papanikola	Recreational scuba diving	Cape Greco, Famagusta	10	Natural hard	34°57.7'	34°4.4'
L	16.07.2015	Wolf Werner	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	9	Natural hard	34°59.1'	34°4.6'
M	18.07.2015	Elia Sotiris	Freediving/ Spearfishing	Oil pipeline, near Larnaca port	16	Pipeline	34°56.2'	33°39.0'
N	19.07.2015	Sotiroula Tsirponouri	Recreational scuba diving	Zenobia Wreck, Larnaca	20	Wreck	34°53.8'	33°39.5'
O	21.07.2015	Vagelis Gavalas	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	12–14	Natural hard	34°59.1'	34°4.6'
P	25.07.2015	Maria Papanikola	Recreational scuba diving	Xylofagou, Larnaca	14	Natural hard	34°56.7'	33°50.2'
Q	05.08.2015	Wolf Werner	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	14	Natural hard	34°59.1'	34°4.6'
R	07.08.2015	Wolf Werner	Recreational scuba diving	Konnos Bay, Protaras, Famagusta	12	Natural hard	34°59.3'	34°4.7'
S	09.08.2015	Loizos Loizou	Recreational scuba diving	Zenobia Wreck, Larnaca	20	Wreck	34°53.8'	33°39.5'
T	17.08.2015	Vagelis Gavalas	Recreational scuba diving	Green Bay, Protaras, Famagusta	03–04	Natural hard	35°0.1'	34°4.1'
U	20.08.2015	Andreas Gkinos	Freediving/ Spearfishing	Vasiliko Port (external side of wave breakers), Larnaca	14	Artificial hard	34°42.9'	33°19.0'
V	29.08.2015	Wolf Werner	Recreational scuba diving	Zenobia wreck, Larnaca	20–22	Wreck	34°53.8'	33°39.5'
W	08.09.2015	Vagelis Gavalas	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	14	Natural hard	34°59.1'	34°4.6'
X	21.09.2015	Royce Hatch	Recreational scuba diving	Cyclops Caves, Protaras, Famagusta	15	Natural hard	34°59.1'	34°4.6'

requires the immediate attention of officials and the engagement of stakeholders. It appears that the lionfish have found their niche, formed reproductive populations and are now established. Lionfish are normally solitary animals and

only gather in groups to mate (Fishelson 1975). While some lionfish stay put, like one that remained on the Zenobia wreck for at least 6 weeks, some travel up to 2 km a day (α from the Cyclops pair).

In the western Atlantic, lionfish have been found in a wide variety of habitats including hard bottom and patchy reefs, seagrass beds and wrecks (Claydon et al. 2012). The lionfish reported in this study were found at depths ranging from 3 to 43 m and the majority were found on vertical rock walls or at the entrance of small caves. Three were found on breakwater defences, three were on wrecks and one was spearfished near an oil pipeline. So far, no lionfish have been spotted in seagrass *Posidonia oceanica* (Linnaeus) Delile 1813 meadows. Genetic research is needed to assess dispersion pathways of the lionfish and to find out whether they have come from Lessepsian migration and/or through aquarium release.

Lionfish have very few documented natural predators due to their venomous spines. Native groupers in the western Atlantic have learned to eat this non-indigenous species (Maljković et al. 2008) and in at least three cases reported herein groupers have been seen close to lionfish. It remains to be seen whether native groupers such as *Epinephelus marginatus* will learn to prey on lionfish and control their invasion. Restrictions on fishing seem sensible to help threatened IUCN Red List species such as the Mediterranean dusky grouper, as these may in turn help control the spread of invasive fish (Mumby et al. 2011).

Judging from the recent increase in *P. miles* in the eastern Mediterranean Sea, its few natural predators, the dispersal capabilities of their planktonic larvae and its ability to adapt to a range of habitats, we suspect that a rapid expansion throughout the Mediterranean Sea may soon follow with significant impacts on local ecosystems and fisheries. Furthermore, CO₂ emissions which are warming the Mediterranean Sea and the construction of a deeper and wider Suez Canal are expected to increase invasion rates (Galil et al. 2015; Hall-Spencer & Allen 2015).

Lionfish are slow moving and easy to collect by divers and we know, from the western Atlantic experience, that early detection and a rapid response is the first line of defence to mitigate impacts of the lionfish invasion (Morris et al. 2009). Targeted removal by divers has reduced lionfish abundance at shallow depths in the western Atlantic (Frazer et al. 2012; Albins & Hixon 2013). Mediterranean stakeholders (especially divers and fishermen) should be engaged with education and outreach, training and the provision of incentives for removal efforts. The fact that only about a tenth of the lionfish reported by divers in this study were removed from the ecosystem is testimony to the lack of knowledge about the potential impacts of a lionfish invasion. We believe that many will be motivated to aid removal efforts. When the venomous dorsal, pelvic fin and anal fin spines are removed, the lionfish is safe to consume and this can be promoted. Removal programs should be combined with efforts to restore populations of potential predators of lionfish, such as the dusky grouper.

Abbreviations

CO₂, carbon dioxide; DFMR, Department of Fisheries and Marine Research; IUCN, International Union for Conservation of Nature

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Availability of data and materials

All available data are presented in the manuscript.

Authors' contributions

DK communicated with officials, divers and fishermen and collected data regarding the lionfish encounters. He was the main author of the article. JHS edited and reviewed the article and supervised the article preparation. PK assisted data collection and reporting. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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