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ARTICLE

Conflicting interests and growing importance of non-indigenous species in commercial and recreational fisheries of the Mediterranean Sea

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Abstract

Non-indigenous species (NIS) are spreading and reshaping Mediterranean Sea biological communities and fishery resources. The present study used fisheries data and structured interviews to assess the impacts of NIS on recreational and commercial fishers in Cyprus. NIS that have been present in Cyprus for more than two decades were mostly perceived by local fishers as native, NIS with high market value were considered to be beneficial, and venomous or poisonous NIS were considered to be deleterious. Pufferfishes (Tetraodontidae) were identified by fishers as causing significant economic damage, which undermines the sustainability of the commercial fishing sector. The most popular and highly priced NIS were rabbitfishes (*Siganus* spp.). In terms of commercial landings, six non-indigenous taxa contributed over a quarter of the total landing value and more than half during the summer season. The results of the present study emphasised the multifaceted interactions of NIS with the fishing sector, and how policy objectives may not align with social and commercial fishery interests.

KEYWORDS
alien species, fishers, invasive species, management, non-native species, perceptions

1 | INTRODUCTION

Mediterranean marine ecosystems are deteriorating due to increasing human activities and pressures (Coll et al., 2010). Invasions by non-indigenous species (NIS) are rapidly changing the marine ecosystems in the region (Edelist et al., 2013; Katsanevakis et al., 2014a). The rate of NIS introductions is accelerating and is greater than in any other region worldwide; reaching over 600 established multicellular species in 2017 (Galil, Marchini & Occhipinti-Ambrogi, 2018; Zenetos et al., 2017). Major pathways for NIS include shipping (transfer via ballast waters or as biofouling), the Suez Canal, aquaculture and aquarium releases (Katsanevakis et al., 2014a). The Suez Canal is the dominant pathway responsible for the majority of the NIS present (Galil et al., 2015). Enlargement of the Suez Canal, overfishing and climate change are combining to allow more warm water Indo-Pacific species to become established in the Mediterranean Sea to the detriment of native species (Galil et al., 2017; Moullec et al., 2019).

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Some NIS become invasive when they cause negative ecological effects. Such effects include reducing native species richness and abundance, increasing the risk of native species extinction, reducing the genetic diversity of local populations, introducing novel parasites or diseases, changing native species behaviour, altering ecological processes and reducing ecosystem services (de Castro et al., 2017; Chaffin et al., 2016; Geburzi & McCarthy, 2018). Invasive NIS have also become a major social issue: inflicting economic losses in a range of millions to billions of dollars per year (Warziniack et al., 2021), impacting human health, and interacting with recreational activities and aesthetic values (Pyšek & Richardson, 2010). A number of recently-introduced invasive NIS in the Mediterranean are poisonous or venomous and so could adversely affect tourism and fisheries (Galil, 2018). For example, pufferfishes (family: Tetraodontidae) have high concentrations of tetrodotoxin (TTX) in their tissues and can be fatal when consumed (Katikou et al., 2009). Some species damage fishing gear and catch, such as the pufferfishes, the striped eel catfish *Plotosus lineatus* (Thunberg), and the nomad jellyfish *Rhopilema nomadica* Galil (Galanidi et al., 2018; Kalogirou, 2013).

Positive effects of NIS can in some cases be underestimated due to a perception bias and focus on the negative effects (Katsanevakis et al., 2014b). Some NIS can replace lost ecological functions, add redundancy and enhance ecosystem services (Chaffin et al., 2016; Kleitou et al., 2021a), in addition, some cases becoming target species of the fisheries (Demirel et al., 2021; Ugarković & Crocetta, 2021) that provide potential to stabilise fishery revenues (Michailidis et al., 2019; van Rijn et al., 2019; Saygu et al., 2020).

Relatively little is known about the impacts of NIS on people and society (García-Llorente et al., 2008, 2011). A few recent studies have explored the adverse socioeconomic effects of NIS in the Mediterranean Sea (Galanidi et al., 2018; Peyton et al., 2019, 2020), but the positive impacts may have been overlooked (Bonanno, 2016; Kleitou et al., 2021a). In principle, risk assessment of NIS to inform decision makers focuses purely on adverse impacts, though under the 2014 EU Regulation (No. 1143/2014) on the prevention and management of the introduction and spread of invasive alien species, possible benefits of a NIS must be mentioned but these are not evaluated so that decision makers may come to an informed decision on NIS, balancing up the adverse impacts and potential positive benefits.

Commercial and recreational fisheries are important to local people of the Mediterranean region (Giovos et al., 2018; Lloret et al., 2018). Inherent difficulties in monitoring (FAO, 2020), such as the diverse structure of fishing fleets (Lloret et al., 2018), the diverse national data collection programmes (Pauly & Zeller, 2016) and a lack of data on recreational fisheries (Pita et al., 2018) all pose challenges for sustainable management of the sector. Non-indigenous species are gradually becoming a source of revenue in the eastern Mediterranean (van Rijn et al., 2019), but insufficient consideration of stakeholder perspectives and priorities when making management decisions mainly or purely on NIS risk assessments that report impacts, can lead to poor policy decisions that lose support at the local management level (Barney & Tekiela, 2020; Oficialdegui et al., 2020). As such, the multifaceted costs and benefits of NIS for local people need to be understood better and incorporated into marine management strategies.

The present study used (i) fishery data from official Cyprus national sources (Department of Fisheries and Marine Research, Ministry of Agriculture, Cyprus) and (ii) structured interviews with commercial and recreational fishers, to assess the socioeconomic interactions, knowledge, norms and intrinsic motivations of fishers with respect to common NIS.

The study focussed on a marine protected area (MPA) adjacent to Cyprus where NIS of Indo-Pacific origin now dominate (Kleitou et al., 2019b; Savva et al., 2020). Two fishing fleets operate in this area: small-scale inshore boats and polyvalent vessels. The small-scale inshore boats (overall lengths of 6–12 m) target predominantly demersal species using mainly bottom-set nets (trammel nets/gillnets) and bottom longlines. The polyvalent vessels (overall lengths of 12–24 m) target pelagic species with drifting longlines, bottom-set trammel/gill nets and bottom longlines. All recreational fishers, irrespective of their fishing technique/tools, were included in the present study. Recreational fishers use traps, spearfishing, boatfishing using bottom fishing, trolling, jigging, bottom longlining, deep dropping and shore fishing using casting, spinning, squid jigging (eging) and shore jigging (Moutopoulos et al., 2021). The catches of recreational fishers are not monitored by official schemes.

2 | MATERIALS AND METHODS

2.1 | Targeted non-indigenous species

The research is focussed on 12 target NIS (Table 1), which were selected based on their known high abundance or identified as priority species in relation to fisheries (GFCM-UNEP/MAP, 2018).

2.2 | National fishery data

Monthly national fishery data (landings quantity (kg), value (€) and effort (landings per trip)) for the selected species were provided by the Cyprus Department of Fisheries and Marine Research (DFMR). These data derive from various sources of information such as logbook records of fishers and sales notes from fishmongers. Data were acquired for the landings of the four nearest (<15 km distance) to the Cape Greco (MPA) landing areas, namely Ayia Triada, Paralimni, Ayia Napa and Potamos for 2017–2019 (Figure 1).

2.3 | Structured interviews

Structured interviews were conducted with both commercial (CFs) and recreational (RFs) fishers during June and July 2020 at the same landing areas (i.e. Ayia Triada, Paralimni, Ayia Napa and Potamos) and adjacent locations on the coast whilst interviewees were fishing.

TABLE 1 Selected non-indigenous species targeted through structured interviews and sorted with the year of their first record in Cyprus. This selection was focused on priority species identified through the GFCM-UNEP/MAP 2018, and local expertise.

Species	Common name	Year of first record in Cyprus - Reference
Siganus rivulatus	Marbled spinefoot	**1928** - Norman (1929)
Saurida lessepsianus	Lizardfish	**1960** - Ben Tuvia (1962)
Sargocentron rubrum	Redcoat	**1961** - Fodera (1961)
Siganus luridus	Dusky spinefoot	**1964** - Demetropoulos and Neocleous (1969)
Sphyraena chrysotaenia/ flavicauda	Yellowstripe barracuda	**1964** - Demetropoulos and Neocleous (1969) / **2014** - Iglésias and Frotté (2015)
Pempheris sp.	Sweeper fish	**1995–1996** - Iglésias and Frotté (2015)
Fistularia commersonii	Bluespotted cornetfish	**1999** - Wirtz and Debelius (2003)
Torquigener flavimaculosus	Yellowspotted puffer	**2009** - Michailidis (2010)
Sepioteuthis lessoniana	Bigfin reef squid	**2009** - Tzomos et al. (2010)
Pterois miles	Devil firefish (lionfish)	**2012** - Kletou et al. (2016)
Lagocephalus sceleratus	Silver-cheeked toadfish	**2014** - Iglésias and Frotté (2015)
Parupeneus forsskali	Red Sea goatfish	**2014** - Iglésias and Frotté (2015)

Note: This selection was focussed on priority species identified through the GFCM-UNEP/MAP, 2018 and local expertise.

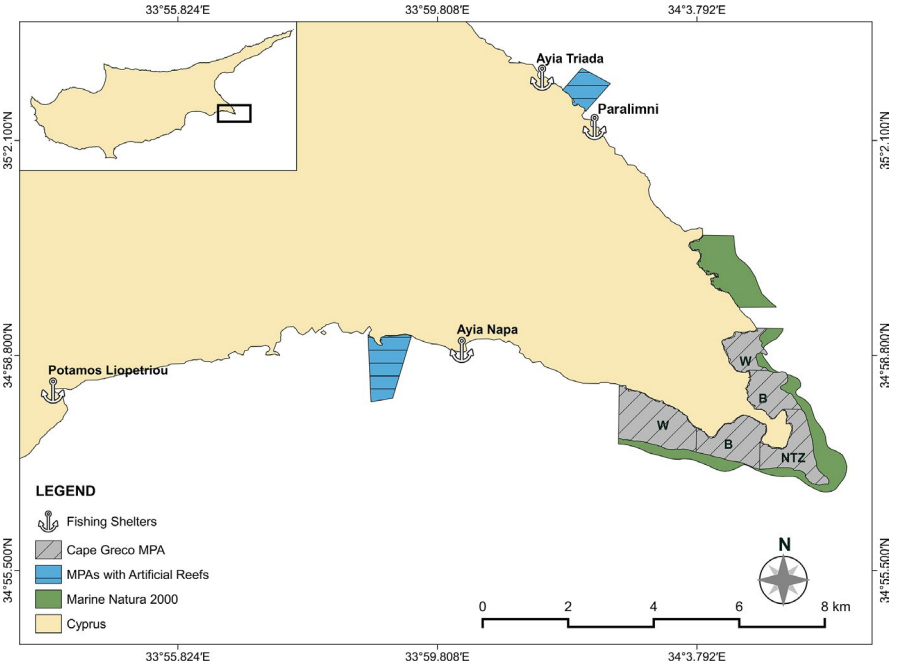


FIGURE 1 The study area focussed around the first established natural marine protected area (MPA) with fishery prohibitions of Cyprus (Cape Greco; with grey colour in the map) and nearby landing areas (namely Ayia Triada, Paralimni, Ayia Napa and Potamos for 2017–2019). NTZ: no take zone (fishing is prohibited for everyone); B: buffer zone (fishing is prohibited only for recreational fishers); W: wider zone (fishing is allowed). Blue colour indicates areas with artificial reefs established by the Department of Fisheries and Marine Research to promote dive ecotourism, and where fishing is prohibited for everyone

Contact details of the licenced CFs were provided by the local fishery associations and the DFMR. Before the interview, fishers were informed that their participation was optional, and that personal data would remain confidential. All interviews were carried out by the same trained person, ensuring that questions were presented in an identical manner. The interviews were held privately, on one-to-one sessions, to prevent influence or interference by other people.

The structured interview posed questions (shown in Supplementary Material 1) in three sections to describe: (1) the demographic profile of the respondents; (2) their perceptions about the impacts of NIS (encompassing all species); (3) species-specific knowledge, perceptions and interactions of fishers with the 12 target NIS. The target species' common name(s) were used, and an image of the species was shown to ensure that the interviewee was providing comments on the correct species. Species-specific questions quantified the fisher's: (a) knowledge about the non-indigenous nature of each species in the Mediterranean Sea; (b) perceptions for each species impacts; (c) discard rates; (d) catch frequency (i.e. probability

of catch in a fishing trip) and proportion (i.e. percentage contribution in the overall catch biomass of a fishing trip); (e) damage to catches (through depredation) or fishing tools; (f) injuries caused by the species; and (h) alterations of fishing tools, location and/or duration due to the presence of the species.

Fishers were separated into categories based on their activities: Small vs large vessel (polyvalent) for the CF category, and boat fishers using demersal techniques, boat fishers using pelagic techniques, shore fishers and spearfishers for the RF category. Descriptive statistics were applied, providing percentage contribution, mean, standard deviation (SD) and standard error (SE) values for absolute values, such as landing weight and value, damages (costs) and injuries caused by NIS. For scale questions, the frequency of occurrence/reports (%) was found for each fisher category. Questions were analysed for associations using a 1-sample chi-squared (χ^2) proportion test or an exact binomial test (using proportion of 0.5). Relationships between the profile of fishers (RFs and CFs) and the responses were assessed using the Pearson's χ^2 test, with Yate's continuity correction for dichotomous questions, or the Fisher exact test (when sample size in one or more cells was below 5). For percentage-based scale questions, the rank-based Kruskal–Wallis H test followed by a Dunn's test with Bonferroni correction was applied to examine differences between species. Correlations between recognition of species as non-indigenous by fishers with the year of their first record to Cyprus waters and their retail price (i.e. average mean of last three years based on official data) were examined using the Kendall's Tau (τ) rank-correlation coefficient. All statistical analyses and graphics were carried out in Microsoft Excel and R-studio (Version 1.2.1335).

3 | RESULTS

3.1 | National fishery data

In2019, 78 licensed CFs were active at the four landing areas. Landing data for yellow spotted puffer *Torquigener flavimaculosus* and silver-cheeked toadfish *Lagocephalus sceleratus* were both reported as *Lagocephalus* spp., yellowstripe barracuda *Sphyraena chrysotaenia* and yellowtail barracuda *S. flavicauda* data were sold as *Sphyraena* spp. and could not be separated from other native species (e.g. European barracuda *Sphyraena sphyraena*), and no data were available for bigfin reef squid *Sepioteuthis lessoniana* (sold as the native common squid *Loligo vulgaris*), sweeper *Pempheris* sp., and lizardfish *Saurida lessoniana* (which were both sold in an aggregated category as 'various'). Between 2017 to2019, six non-indigenous taxa (bluespotted cornetfish *Fistularia commersonii*, *Lagocephalus* spp., Red Sea goatfish *Parupeneus forsskali*, common lionfish *Pterois miles*, redcoat *Sargocentrum rubrum*, dusky spinefoot and marbled spinefoot (*Siganus luridus* and *Siganus rivulatus*) contributed 29% (97,292kg) of the total landings weight and for 28% (€340,802) of landings value,equal to an annual income of €1,456 per each fisher individual.

Lagocephalus spp., *S. rubrum* and *Siganus* spp. were the most common NIS contributing for 13%, 8.7% and 6% of the total landing weight in 2017–2019 respectively. Peak NIS landing was during summer when their contribution was over half of both total landings and value (Figure 2a). Total landings and catch per unit effort (kg per trip) followed a similar temporal pattern for *Siganus* spp., but a peak was evident during the summer months mainly for *Lagocephalus* spp. and *S. rubrum* (Figure 2b, c). The value of *Lagocephalus* spp. landings in 2019 was about €73,550, equal to €943 per fisher. Rabbitfishes *Siganus* spp. contributed 6% of the total weight, but it represented 17% (or €269,399, equal to €3454 per fisher) of the total value of the landings (Figure 2b). Since 2019, landings increased sharply for *P. forsskali*, and the first reports of *P. miles* were also recorded. The two *Siganus* species and *P. forsskali* were the most commercially valuable species with retail prices over €10 per kg (Figure 2d).

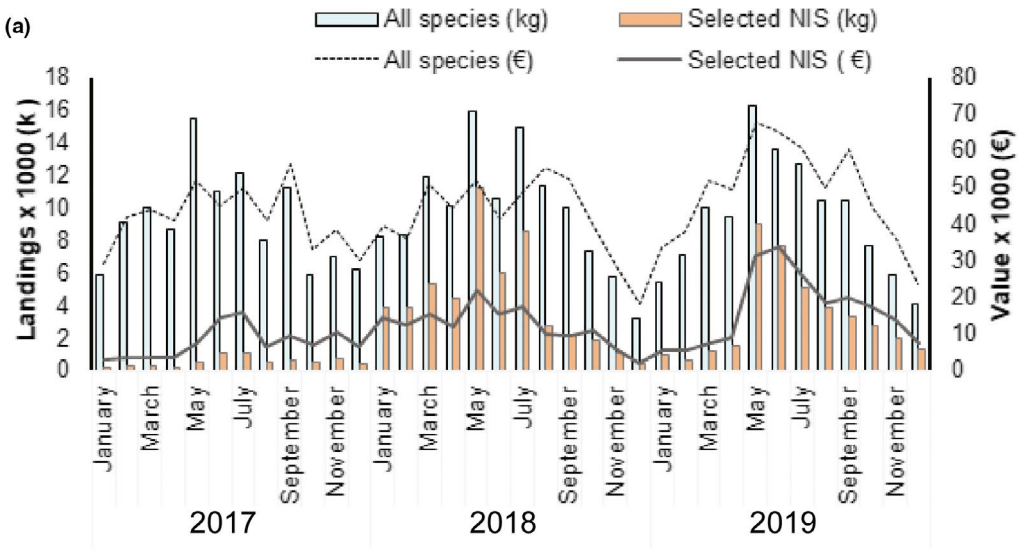
3.2 | Interview results

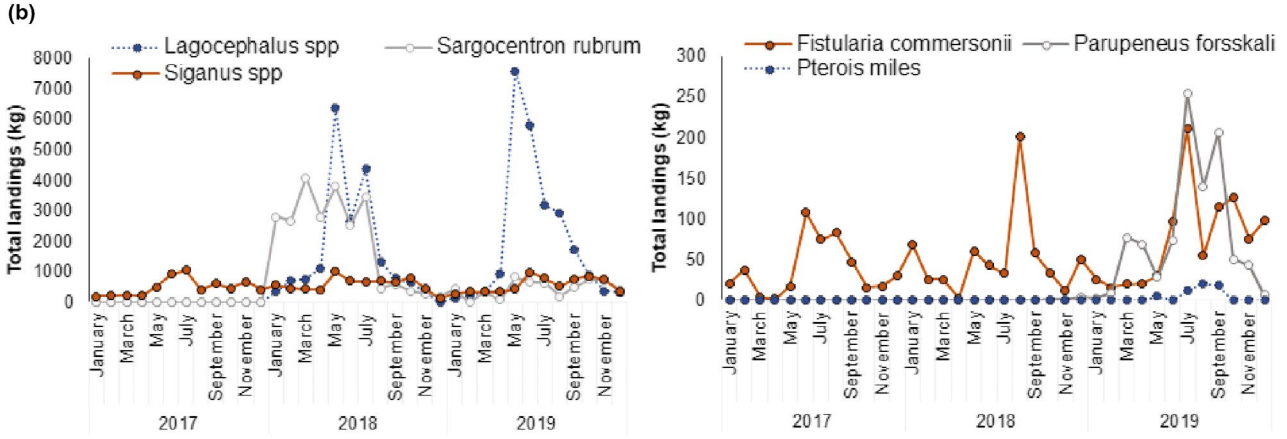
Fifty five fishers were interviewed, 20 of whom were CFs (17 small-scale fishers and three polyvalent corresponding to 25.6% of the licenced CFs of the area) and 35 RFs some of which used more than one fishing mode (five fishing demersal species with boat; five fishing pelagic species with boat; 28 fishing with a rod from the shore; and four fishing with freedive and speargun). These fishers were male. The mean age of the CFs was 49.9 (SD: 16.3) with the mean age of the RFs was 51.6 years (SD: 12.1). About 70% of RFs and 85% of CFs were graduates of secondary education or lower. A high percentage of the RFs (>70%) did not own a recreational fishing licence (no licence exists for shore fishing in Cyprus) or a fishing vessel, whereas all of the CFs owned a professional fishing licence (70% owned a Type A licence, 10% a Type B, 5% a Type C and 15% owned polyvalent licence). Information about the different licence types, the demographic profile, the fishing intensity and the spatiotemporal activity distribution of the interviewed fishers are presented in Moutopoulos et al. (2021).

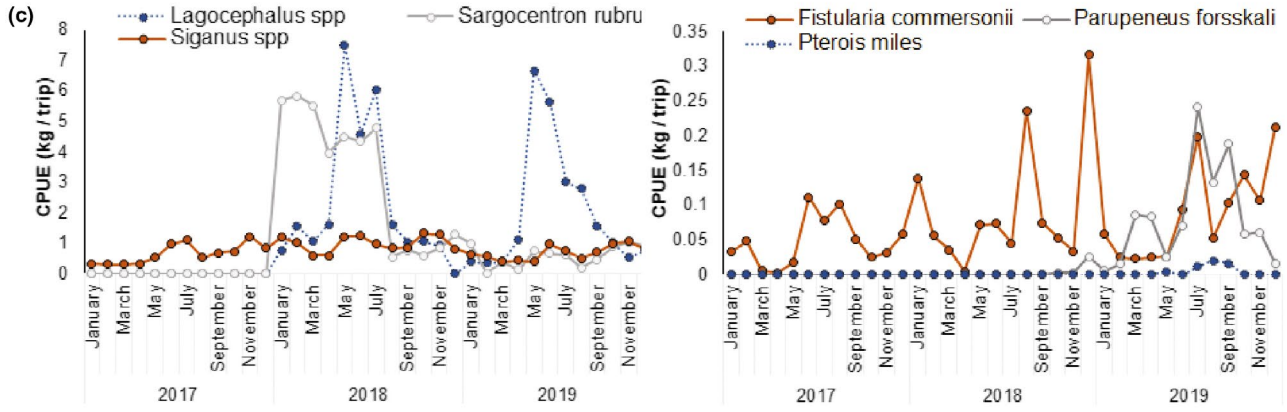
The vast majority (overall ≈95%) of both CFs and RFs stated that they were aware of what a non-indigenous species is. Using a scale of −2 to +2 (−2 = very negative, 0 = neutral and +2 = very positive), the vast majority of fishers reported that NIS cause very negative ("−2") impacts (≈81%, $n = 45$) (binomial test, $p < 0.05$).

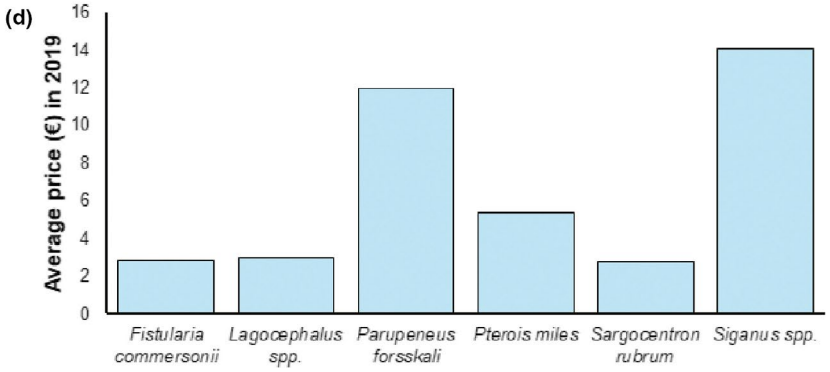
Only five (i.e. *L. sceleratus*, *T. flavimaculosus*, *P. forsskali*, *P. miles* and *F. commersonii*) of the twelve species were correctly recognised by most fishers as non-indigenous for the Mediterranean waters

FIGURE 2 (a) Monthly landings (kg) and value (in €) of fishery catches, and for selected non-indigenous species combined (*Lagocephalus* spp., *Sargocentron rubrum*, *Siganus* spp., *Fistularia commersonii*, *Parupeneus forsskali* and *Pterois miles*), (b) monthly landings for each species, (c) monthly catch per unit effort (CPUE) for each species, and (d) mean retail price (in €) per kg for each species in 2019


(a)
All species (kg)
Selected NIS (kg)
All species (€)
Selected NIS (€)
Landings x 1000 (k)
Value x 1000 (€)
January
March
May
July
September
November
2017
2018
2019


(b)
Lagocephalus spp
Siganus spp
Sargocentron rubrum
Total landings (kg)
Fistularia commersonii
Parupeneus forsskali
Pterois miles
2017
2018
2019


(c)
Lagocephalus spp
Siganus spp
Sargocentron rubru
CPUE (kg / trip)
Fistularia commersonii
Parupeneus forsskali
Pterois miles
2017
2018
2019


(d)
Average price (€) in 2019
Fistularia commersonii
Lagocephalus spp.
Parupeneus forsskali
Pterois miles
Sargocentron rubrum
Siganus spp.

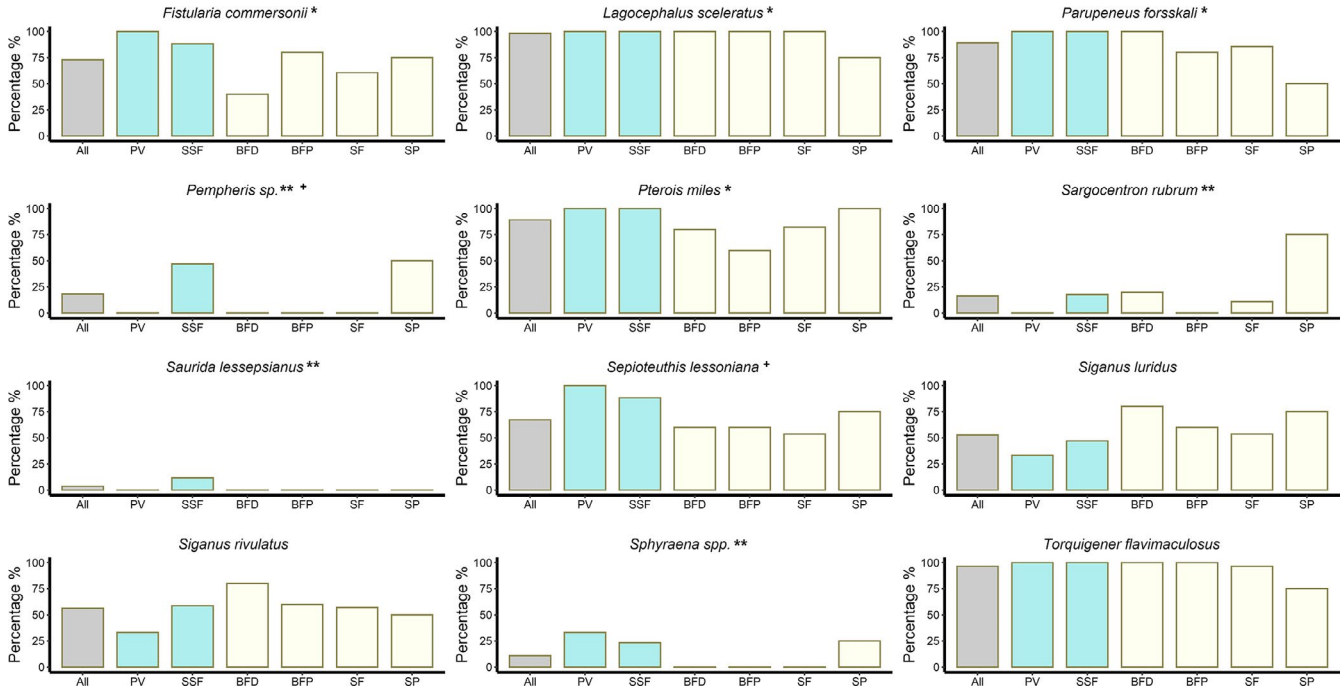


FIGURE 3 Knowledge of fishers about whether the species is non-indigenous or native to the Mediterranean Sea. Commercial fishers (SSF: small-scale fishers; PV: polyvalent) and recreational fishers (BFD: boatfishing demersal; BFP: boatfishing pelagic; SF: shore fishing; SP: spearfishing). Grey colour shows all responses, blue colour indicates commercial fishers and yellow colour indicates recreational fishers. Asterisk (*) represents statistically significant identification of species as non-indigenous by most fishers, and two asterisks (**) represent significant identification of species as native ($p < 0.05$, binomial test using proportion of 0.5). Cross (+) represents significant differences between the responses of commercial and recreational fishers (Fisher's exact test or Pearson's chi-squared test, $p < 0.05$)

(Figure 3). On the other hand, *S. rubrum*, *Sphyraena* spp., *Pempheris* sp. and *S. lessepsianus* were falsely viewed as native to the region by most fishers (Figure 3). The responses were contradictory for *S. luridus*, *S. rivulatus* and *S. lessoniana* as there was equal proportion of fishers who viewed them as non-indigenous or native (Figure 3). The responses did not vary significantly between RFs and CFs except for *S. lessoniana*, which was recognised as non-indigenous by 90% of CFs but only from 54% of RFs, and *Pempheris* sp., which was recognised as non-indigenous by 40% of CFs but only from 6% of RFs (Figure 3). There was a significant positive correlation between the recognition of species as non-indigenous and the year that the species was first recorded in Cyprus (Kendall's $\tau = 0.54$, $p < 0.05$, Figure 4a), with species that were first recorded after year 2000 being recognised as non-indigenous. There was a negative, but not significant correlation, between the recognition of the species as non-indigenous and their retail price (Kendall's $\tau = -0.18$, $p > 0.05$, Figure 4b), as well as the price of the species and the year of its first record in Cyprus (Kendall's $\tau = -0.14$, $p > 0.05$, Figure 4c).

Opinions regarding the impacts of each species varied. Species that were correctly recognised as non-indigenous were more likely to be viewed as negative (Pearson's $\chi^2 = 38.057$, df = 2, $p < 0.05$). Moreover, species market value was strongly correlated with the perceived impacts of the species (Kendall's $\tau = 0.58$, $p < 0.05$, Figure 4d). Highly priced *Siganus* spp., *P. forsskali* and *S. lessoniana* were generally viewed as positive, whereas poisonous *L. sceleratus* and *T. flavimaculosus* and venomous *P. miles* were perceived as negative (Figure 5). Commercial and recreational fishers responded similarly for all species impacts except for *Pempheris* sp., *S. lessepsianus* and *Sphyraena* spp., for which most RFs responded "they don't know," but CFs perceived mostly positive impacts (Figure 5).

When asked about the frequency (i.e. probability of catch in a fishing trip) and proportion (i.e. percentage contribution in the overall catch biomass of a fishing trip) of each NIS, the responses were consistent with the official landing data of commercial fishery by recognising the two pufferfishes (*L. sceletarus* and *T. flavimaculosus*) as the most commonly caught species. Small deviations were also identified; for example, the two rabbitfishes (*S. rivulatus* and *S. luridus*) were reported as being more common than the *S. rubrum*. (Figure 6). Responses for both frequency and proportion varied significantly amongst species (Kruskal–Wallis, $\chi^2 = 57.73$, df = 11, $p < 0.05$, $\varepsilon^2 = 0.088$ and Kruskal–Wallis, $\chi^2 = 57.73$, df = 11, $p < 0.05$, $\varepsilon^2 = 0.088$ respectively). In addition, CFs and RFs responded differently for the catch frequency and catch proportion of all species (Fisher's exact test, $p < 0.05$) apart for the frequency of *T. flavimaculosus* and proportion of *S. rivulatus* for which the two groups responded similarly ($p > 0.05$). Only *S. lessoniana* was reported as being caught more frequently by RFs (i.e. 29% with over 50% frequency and 37% with over 20% proportion) compared with CFs (20% and 10% for frequency and proportion respectively). All other species were more common for CFs; for example, only 3% of RFs reported over 50% frequency for *P. miles*, *F. commersonii* and *P. forsskali*, compared with 85%, 75% and 55% (respectively for each species) of CFs

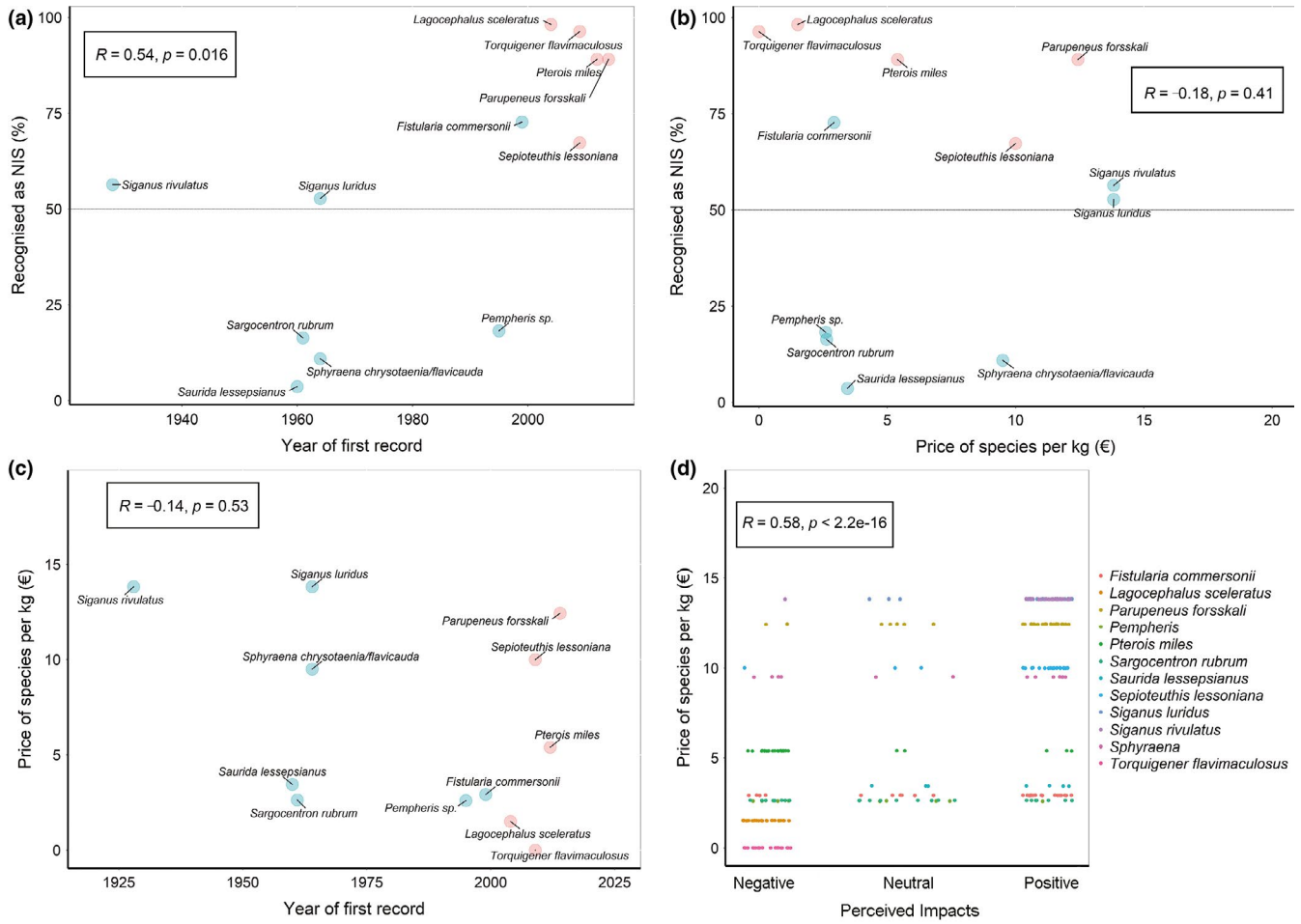


FIGURE 4 Associations between (a) year of species first record in Cyprus and recognition as non-indigenous, (b) price of species and recognition as non-indigenous, (c) year of first record and price of species and (d) price of species and perceived impacts to the ecosystem. The boxes show the Kendall rank correlation coefficient and *p*-value

indicating a potential nonselectiveness of RFs for these species. Recreational fishers reported no encounters with *S. lessepsianus* and *Pempheris* sp., whereas *Sphyraena* spp. were found either very frequently or never by RFs (23% with 100% frequency and 77% with 0% frequency). Information for each (sub)-category of fishery and the reported catches of each species are displayed in Supplementary Material 2.

According to fishers' responses, pufferfish species *L. sceleratus* and *T. flavimaculosus* had the most chances of being discarded (Figure 7); however, responses for the two species varied between CFs and RFs (Figure 7) with the first group reporting less discard rates. This was especially the case for *L. sceleratus*, which was more likely to be kept by CFs (binomial test, $p < 0.05$). High discard rates were also reported for *Pempheris* sp. and *P. miles*, but with no significant probabilities of either being discarded or kept (binomial test, $p > 0.05$). Commercial and recreational fishers responded differently for *P. miles* (Pearson's chi-squared test with Yates' continuity correction, $\chi^2 = 6.34$, df = 1, $p < 0.05$), and CFs were more likely to keep the fish instead of discarding it (1-sample proportions test with continuity correction, $p < 0.05$). Commercial and recreational fishers responded with similar discard rates for all other species (Fisher's exact test, $p > 0.05$) (i.e. *P. forsskali*, *F. commersonii*, *S. lessoniana*, *S. luridus*, *S. rivulatus*, *S. chrysotaenia/flavicauda*, *S. lessepsianus* and *S. rubrum*) who were more likely to keep the catches than discard them (binomial test, $p < 0.05$) (Figure 7).

Fishers reported no direct financial impact of each NIS on in-net/pot predation of other catch or causing damage to the fishing gear, except for pufferfishes (*L. sceleratus* and *T. flavimaculosus*). For the pufferfish, the greatest impact was identified by CFs who reported direct economic losses were equal to €4173.53 (±2524.88) per year for each small-scale fisher (Supplementary Material 3A). The extrapolated financial impact of pufferfishes to the full fishing fleet in the studied area (78 fishers) is estimated as €325,535 per annum, which represents 56% of the total value of all fishery catches reported in 2019 from the four landing areas.

Regarding the indirect impact caused by the NIS, about 30% of the fishers reported that they change their fishing area, duration or tools due to the presence of pufferfishes (*L. sceleratus* and *T. flavimaculosus*) in their target area (Supplementary Material 3B). The proportion was significant for small-scale fishers; approximately 76% reported that they change their fishing tools or practices, such

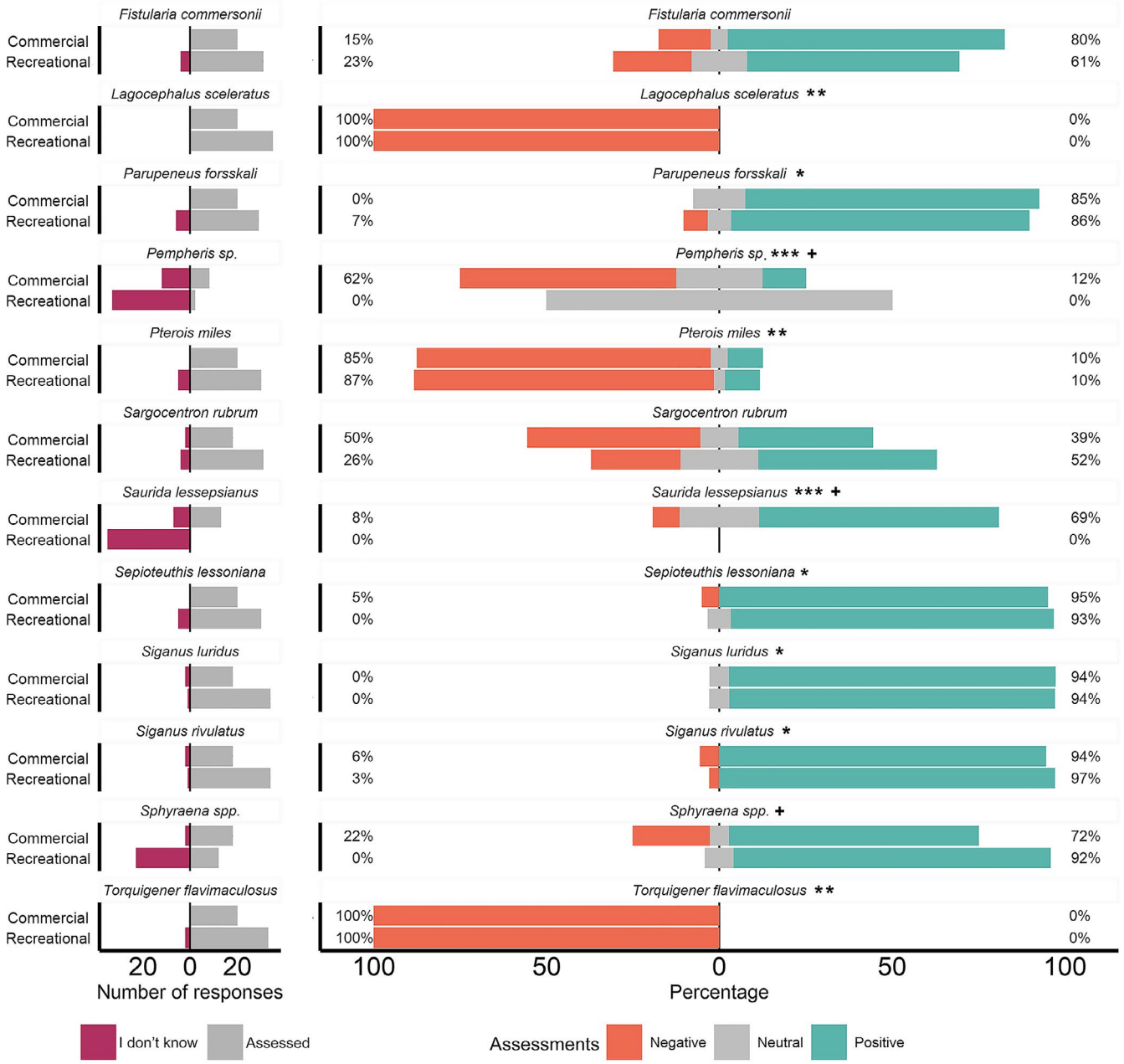


FIGURE 5 Perceptions about the impacts (positive, negative or neutral) of the selected NIS as stated by the commercial and recreational fishers (right plot). Left plot shows the number of fishers who reported that they don't know versus those who assessed the impacts. Asterisk (*) represents statistically significant view of species impacts as positive, two asterisks (**) represent statistically significant view of species impacts as negative and three asterisks (***) represent statistically significant "I don't know" responses ($p < 0.05$, binomial test using proportion of 0.5). Cross (+) represents significant differences between the responses of commercial and recreational fishers (Fisher's exact test or Pearson's chi-squared test, $p < 0.05$)

as fishing with larger mesh nets, fishing for smaller durations and changing locations (binomial test, $p < 0.05$).

Fishers did not report any personal incidents of injury from the selected NIS apart from one fisher who reported that he got stung by lionfish three times in the past year (Supplementary Material 3B). Finally, CFs fishers stated that non-indigenous by-catch and subsequent damage to gear increased the time spent fishing to achieve their income (55% of the CFs stated an increase of one to one and a half hour per fishing trip).

4 | DISCUSSION

Non-indigenous species are increasingly reshaping the ecosystems of the Mediterranean Sea (e.g. Giovos et al., 2019; Kleitou et al., 2019a; Michailidis et al., 2020), altering commercially important species assemblages. As native species are overfished, the contribution and interactions of NIS with fisheries have increased (Kleitou et al., 2021a). Some invasive NIS exert adverse impacts whereas others provide welcome revenue, and some may

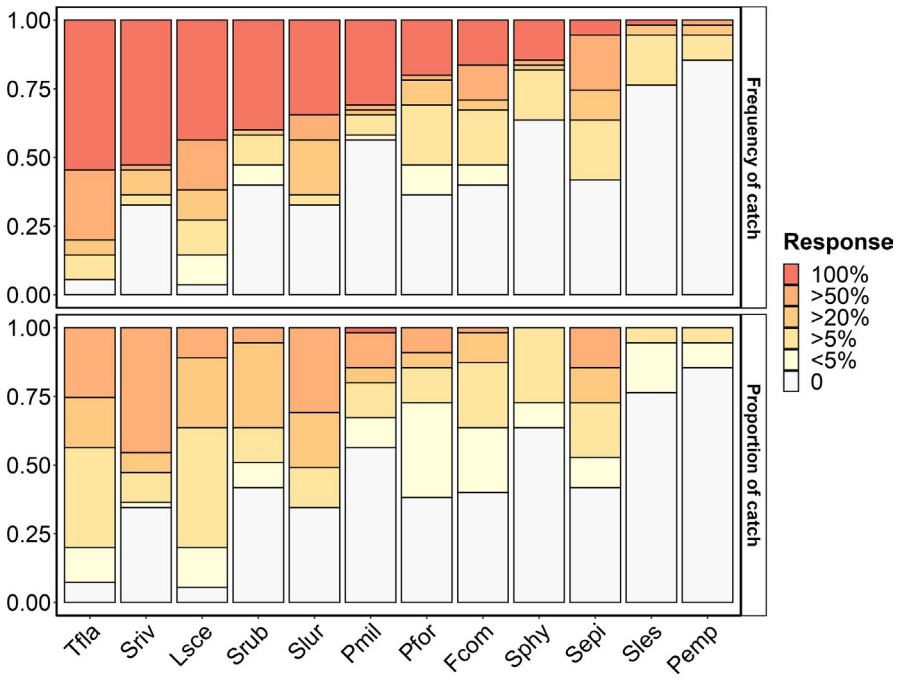


FIGURE 6 Catch frequency (i.e. probability of catch in a fishing trip) and proportion (i.e. percentage contribution in the overall catch biomass of a fishing trip) for each species (Tfla: *Torquigener flavimaculosus*, Sriv: *Siganus rivulatus*, Lsce: *Lagocephalus sceleratus*, Srub: *Sargocentron rubrum*, Slur: *Siganus luridus*, Pmil: *Pterois miles*, Pfor: *Parupeneus forsskali*, Fcom: *Fistularia commersonii*, Sphy: *Sphyraena* spp., Sepi: *Sepioteuthis lessoniana*, Sles: *Saurida lessepsianus* and Pemph: *Pempheris* sp.)

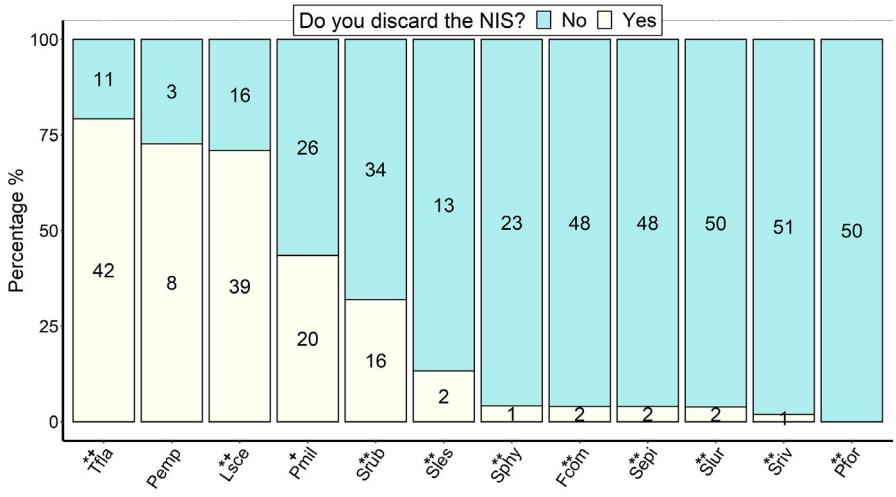


FIGURE 7 Discard rates of each non-indigenous species according to the fishers' responses (Tfla: *Torquigener flavimaculosus*, Pemph: *Pempheris* sp., Lsce: *Lagocephalus sceleratus*, Pmil: *Pterois miles*, Srub: *Sargocentron rubrum*, Sles: *Saurida lessepsianus*, Sphy: *Sphyraena* spp., Fcom: *Fistularia commersonii*, Sepi: *Sepioteuthis lessoniana*, Slur: *Siganus luridus*, Sriv: *Siganus rivulatus* and Pfor: *Parupeneus forsskali*). Asterisk (*) represents statistically significant retainment, and two asterisks (**) represent statistically significant discard ($p < 0.05$, 1-sample proportions test with continuity correction or binomial test using proportion of 0.5). Cross (+) represents significant differences between the responses of commercial and recreational fishers (Fisher's exact test or Pearson's chi-squared test, $p < 0.05$)

provide both. These details can inform a management policy that acknowledges the multifaceted interactions of NIS with stakeholder groups.

Six of the selected NIS contributed over a quarter of the commercial fishery catch in the study area, and the catches comprised more than half of both total landings and value in the summer, highlighting the need for fishery reform to optimise their exploitation (Kleitou et al., 2021a). The contribution of the six species was higher than the catch contribution of all non-indigenous species in the Cyprus fleet, which was estimated by Michailidis et al. (2020) using telephone surveys (about 19%) but comparisons should be made with caution.

The Cyprus government has identified issues with the data reporting system, such as the misidentification or grouping species under a common commercial name, especially in cases of relatively high number of species and low quantities (DFMR, 2020). The absence of discard data (D'Andrea et al., 2020; Kleitou et al., 2017), and the omission of recreational fisheries from the national data collection programmes further impair the management of NIS. Integration of multiple sources of data in monitoring schemes would improve

accuracy and allow for better informed management decisions (Giovos et al., 2020).

Differences between the interview and official landing data highlighted that monitoring would benefit from an improved reporting system. Official fishery records are data deficient some NIS, e.g. species at an early stage of their invasion or species that are sold in aggregated categories along with native species, this prevents timely decision making that can enable management of the NIS before they cause economic impact. For instance, the lack of official data for some NIS, which have been reported as relatively frequent catches (e.g. *S. lessoniana*), indicated either the presence of these species in aggregated species categories or a potential mislabelling of the catches. The low taxonomic resolution of the official landings data also prevents from the disaggregation of non-indigenous species from the native ones (e.g. *Sphyraena* spp.). The common lionfish (*Pterois miles*), which has also been established in the waters of Cyprus since 2015 (Kletou et al., 2016; Kleitou et al., 2021) was first recorded in the official data in 2019. Since then, it was listed in low concentrations despite being reported as very common in interviews with fishers (>95% frequency of catch), indicating a potential misreporting for the early years of the invasion or an absence of reporting due to discarding or misreporting.

The contribution of NIS varied both between CFs and RFs, and amongst gears used. The most popular and highly priced fish was rabbitfish (*Siganus* spp.). The present results agree with those of an earlier study (Michailidis et al., 2019) in which *Siganus* spp. were reported to be the most important species (in terms of weight and value) for the marine recreational fishery of Cyprus. A peak in the catches of the CFs was evident in the summer of 2018 and 2019 for *Lagocephalus* spp. and in 2018 for *S. rubrum*. Since 2010, the Department of Fisheries and Marine Research has provided compensation to fishers from €1 to €3 per fish individual or kilogram of *Lagocephalus* spp. caught (the price varied over the years of the programme implementation; in 2019, the compensation was € 3 per kg) to incentivise fishers to hunt the species and mitigate the impacts. In 2019, the compensation covered (based on the landing value) about 23% of the reported damages (catch and/or gear) that were caused by the pufferfishes (as estimated by the fishers interviewed this study). Rigorous monitoring is needed to understand better the ecological and socioeconomic effects of this DFMR compensation scheme.

A peak in *Lagocephalus* spp. catches coincided with the *L. sceleratus* reproduction peak (Rousou et al., 2014), and it is likely that the species aggregate to spawn during the summer (anecdotal information by fishers). Fishers adapted to fishing pufferfishes in the summer months to benefit from the government subsidies. Aggregations of the *Lagocephalus* spp. populations could offer opportunities for alternative fishing practices (e.g. fishery-related tourism/pescatourism) and management strategies that would guide massive and targeted removal of the species.

From the structured interviews, it was evident that RFs reported significantly less frequency of catches than CFs for many of the selected NIS, including *P. miles*, *F. commersonii* and *P. forsskali*. Recreational fishers' motivations often extend beyond key economic drivers and might be driven by traditional norms for larger and 'trophy' fish, which are often keystone top predators (Giovos et al., 2018; Mackay et al., 2018; Michailidis et al., 2020; Sbragaglia et al., 2021). Future strategies for NIS management need to consider challenging social norms, feelings and moral obligations to enhance fishing pressure to nuisance NIS and alleviate pressure from native keystone species such as groupers (Kleitou et al., 2021a). Spearfishing of lionfish *Pterois* spp. has been widely recognised as the best control mechanism (Côté et al., 2014; Kleitou et al., 2021c). Spearfishing with free dive is very popular in Cyprus, with over 2000 licences per year (DFMR, 2020), and management strategies can aim to engage and motivate them.

Generally, fishers tended to perceive NIS (as a whole) as negative but when asked about species-specific impacts, their responses were contradictory, and many species were viewed positively and by many respondents considered to be native. Less than half of the species were correctly recognised by fishers as NIS in the Mediterranean, and this knowledge was strongly correlated with the year of species introduction in Cyprus (species that arrived prior 2000 were viewed as native).

Negative perceptions were reported for the poisonous *L. sceleratus* and *T. flavimaculosus*, which do not have a market value (apart from compensation/reward by the government), and the low-priced venomous *P. miles* which can injure fishers. On the other hand, high-lypriced species, such as *P. forsskali*, *Siganus* spp. *and S. lessoniana* were perceived positively by > 90% of the respondents. These species are amongst the most common in the area, therefore, fishers did not perceive these species negatively, based on high abundance, as has been reported in other studies (e.g. Cerri et al., 2020). Fishers' perceptions of *Siganus* spp. are apparently conflicting with evidence provided by studies in which the presence and expansion of *Siganus* spp. has been shown to cause profound impacts on the native communities in the Mediterranean infralittoral zone through overgrazing of important algae (Giakoumi, 2014; Vergés et al., 2014). *Siganus* spp. were also considered amongst the 100 worst invasive species in the Mediterranean in terms of their socioeconomic impacts (Streftaris & Zenetos, 2006). Damage to ecosystems is often not visible to the public, and ecosystem state change can occur without immediate negative economic impacts. Divergent views and knowledge between stakeholder groups need to be exchanged, acknowledged and prioritisation of issues (i.e. ecological vs social and economic issues) needs to be harmonised to coordinate management strategies.

The low market price of NIS was mentioned by respondents as a major driver of discards, and it limited targeting of NIS by fishers. There is potential for fishers to become part of the management solution to NIS. In instances where fishing effort can play a role in the management of NIS that are invasive, a market-based management approach to increase demand for selected NIS is strongly recommended (Kleitou et al., 2019c, 2021a). In the present study, high discard rates were reported for lionfishes (≈ 45%) as there was a limited commercial market. Conversely, in the Western Atlantic, the demand for lionfish as a food source is outweighing supply (Chapman et al., 2016), with market forces providing the management control

necessary for this particularly invasive NIS. The present study has demonstrated how NIS, over time, have become intertwined with commercial fishing practice and income. Kleitou et al. (2021a) recommended a cost-benefit analysis to align management of NIS within the ecological system with changing social and economic dynamics.

It was evident that pufferfishes (*L. sceleratus* and *T. flavimaculosus*; reported as *Lagocephalus* spp.) had the worst negative interactions with the fishery—gears, techniques, catches and operations—particularly to small-scale fishers. Incidences of injury with venomous NIS were rare with only one CF reporting that he got stung by *P. miles* three times. However, the risk for injuries may increase as venomous species, such as *P. miles*, are becoming established in the Mediterranean Sea (Galil, 2018). When direct impact of pufferfishes were extrapolated for the entire commercial fishing fleet of this area, the costs were equal to over 50% of the total value of all landings reported in 2019. Apart from this direct impact, 30% of all fishers and 76% of small-scale commercial fishers reported that they have changed their fishing strategies (e.g. larger mesh nets, fishing for smaller durations and changing locations) because of the presence of pufferfish. The destruction of nets and loss of catches has had a negative impact on fishing income and, as a result, put at a risk the economic sustainability of the small-scale fishery (STECF, 2020). This is similar to the impact of pufferfishes on the small-scale fishery of Turkey, where a loss of 2 million € (fishing gear and labour losses) per year was estimated (Ünal et al., 2015).

The findings of the study need to be used with caution. A sample of fishers operating in the study area was interviewed, and results cannot be generalised to the entire Cyprus fishery fleet. However, the use of fishers knowledge is frequently used as an alternative source of information when empirical data are not available (Lopes et al., 2019), and the present study provides additional insights and potentially corrects the above-mentioned inherent limitations of the official data. Interview methods also come with limitations such as reliance on fishers, trust between researcher and fisher, fatigue and potential reticence to provide accurate information (Gill et al., 2019; Maurstad, 2002). All of these issues were largely overcome due to the excellent relationships with the fishers, the proper design and the experience of researchers in conducting interviews.

5 | CONCLUSIONS

The current management strategy against NIS of the Mediterranean is based on the traditional narrative approach of NIS as having only negative effects; it fails to account for positive contribution of species in ecosystems and fisheries. It was evident that the worst socio-economic effects of NIS are being caused by pufferfish species, and management solutions are urgently needed to mitigate the effects of their invasions. Other species such as rabbitfish were perceived as highly beneficial by the fishers. To decide on the NIS management strategy, an ecosystem-based fishery approach is needed at which fishery revenues and losses are assessed together with the ecological loss costs or benefits in an integrative framework (Kleitou et al., 2021a). Fishers could be important allies if they are properly informed and involved in collaborative and communicative management processes (Morales-Nin et al., 2017). Improved data collection programmes, research, citizen science, market campaigns and monitoring are also vital in improving the management of NIS and consequently the performance and sustainability of the fisheries in region.

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CONFLICT OF INTEREST

The authors declare no conflict of interest for this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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