Mediterranean Marine Science

Vol 19, No 1 (2018)

Vol 19, No 1 (2018)

Assessing the socio-economic impacts of priority marine invasive fishes in the Mediterranean with the newly proposed SEICAT methodology

MARIKA GALANIDI, ARGYRO ZENETOS, SVEN BACHER

doi: 10.12681/mms.15940

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available online at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.15940

Assessing the socio-economic impacts of priority marine invasive fishes in the Mediterranean with the newly proposed SEICAT methodology

MARIKA GALANIDI[1], ARGYRO ZENETOS[2] and SVEN BACHER[3]

[1]Institute of Marine Science and Technology, Dokuz Eylül University,
Haydar Aliyev Bul., No:100, 35430, Inciraltı-Izmir, Turkey
[2]Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters,
GR-19013 Anavyssos, Greece
[3]Department of Biology, Ecology & Evolution, University of Fribourg, Chemin du Musée 10
CH-1700 Fribourg, Switzerland

Corresponding author: marika.galanidi@gmail.com
Handling Editor: Paraskevi Karachle

Received: 13 February 2018; Accepted: 19 April 2018; Published on line: 11 May 2018

Abstract

The assessment of impacts of alien species is one of the most critical steps for the prioritisation of policy and management actions and this requires assessment schemes that can compare impacts across different taxa, ecosystems and socio-economic contexts. The Environmental and Socio-Economic Impact Classification of Alien Species (EICAT and SEICAT) are two methodologies that facilitate such comparisons. They classify alien taxa along a 5-level, semi-quantitative scale based on the magnitude of their impacts on the environment and human well-being, respectively. In this study, we applied both protocols to seven invasive marine fishes that that are already considered "high-risk" and have been singled out for monitoring in relation to fisheries in the Mediterranean (*Plotosus lineatus, Pterois miles/volitans, Fistularia commersonii, Lagocephalus sceleratus, Siganus rivulatus/Siganus luridus* and *Saurida lessepsianus*). Here, we focus in particular on their socio-economic impacts. By systematically reviewing the published literature and scoring the demonstrated impacts we show that the taxa with the highest environmental impacts (Major) are *P. miles/volitans* and the two siganids. In contrast, *L. sceleratus* had the highest socio-economic impact (Moderate) and highest number of impact records. The high and uniform densities of *P. lineatus* caused widespread, albeit less severe, impacts in the invaded areas. Human activities that are primarily affected by the selected taxa are commercial and recreational fishing and other recreational uses of the sea through impacts on, mainly, material assets and human health. We found significant data gaps regarding the species' environmental impacts, especially relating to predation, and make specific recommendations for future research. The links between environmental and socio-economic impacts, especially their cultural dimensions, are poorly documented and require novel approaches. Surveys specifically adapted to capture the distinction between socio-economic impact classes would strengthen our confidence in the assessments and better inform prioritisation and decision-making.

Keywords: SEICAT, EICAT, alien, invasive, fish species, socio-economic impacts, impact assessment, Mediterranean.

Introduction

Alien species pose one of the biggest challenges for biodiversity conservation and the management of natural ecosystems (Simberloff *et al*., 2013; Williams *et al*., 2013). In the marine environment, species introductions outside their native range occur primarily through ship-mediated pathways, aquaculture, the aquarium trade and, most notably for the Mediterranean Sea, corridors such as the Suez canal (Katsanevakis *et al*., 2013; Zenetos *et al*., 2012). While some introduced species may enter new areas but fail to get established, others may establish themselves without any severe impacts on the native habitats and communities (Blackburn *et al*., 2011; Zenni & Nuñez, 2013). Yet some species thrive in their new environment and threaten native biodiversity (termed invasive alien species or IAS by the Convention on Biological Diversity, UNEP, 2014). Marine invasions have been associated with species displacements, the alteration of trophic interactions, habitat degradation and disruption of ecosystem function (Lesser & Slattery, 2011; Vergés *et al*., 2014); they can also cause economic harm by interfering with fisheries and recreational activities (Bax *et al*., 2003; Katsanevakis *et al*., 2014) or harm to human health in the case of poisonous or venomous species (Streftaris & Zenetos, 2006). Thus, IAS impacts are of particular concern and have been the subject of intensive research and management/policy initiatives, culminating, at the EU scale, in EU Regulation (No.1143/2014), which entered into force on January 1st 2015 (EU, 2014).

The Regulation sets out rules to prevent, minimize and mitigate the adverse impact on biodiversity of the introduction and spread within the Union, both intentional and unintentional, of IAS. It also introduces a priority list of species of EU concern (the so-called "Union list"), compiled on the basis of several criteria, most importantly the magnitude of IAS impacts on the environment and human well-being, their biogeographic representation in the EU and the feasibility of cost-effective prevention and management (Tollington *et al*., 2017). Currently, only one marine species is included in the Union list, the brachyuran crab *Eriocheir sinensis*, although a number of marine fishes is under consideration with completed or on-going risk assessments. Listing at the EU but also the national and regional levels is underpinned by a prioritization process that starts with risk screening of the species that pose the highest risks (Copp *et al*., 2016; Roy *et al*., 2015) and thus require a thorough risk assessment and takes into consideration the potential for effective management such that relative priorities for action can be established (i.e. risk analysis, Vanderhoeven *et al*., 2017). Prioritization being at the core of this and other IAS-related legislation outside the EU (BIO Intelligence Service, 2011; McGeoch *et al*., 2016), it is crucial that relevant assessment schemes are applied that are transparent, objective and evidence-based, with demonstrated impacts weighing particularly heavily in the decision-making process. While expert opinion of the potential impacts of alien species is often employed in the absence of hard evidence, it is acknowledged that it offers weak inference (Katsanevakis *et al*., 2016), as it can be subjected to personal biases (McBride *et al*., 2012; Goodenough, 2010). Relying on documented evidence only also enables the development of indicators that assess the context dependence and temporal trends in alien species' impacts (McGeoch *et al*., 2010; Latombe *et al*., 2017; Rabitsch *et al*., 2016).

Moreover, the Regulation (and other legislation) does not make any distinction between taxonomic groups but deals with all alien species simultaneously, such that prioritization schemes should be able to effectively compare impacts across very different taxa, habitats and affected commodities (Kumschick *et al*., 2015). In response to this need, Blackburn *et al.* (2014), building on previous work by Nentwig *et al.* (2010) and Kumschick *et al*. (2012), proposed a methodology to classify alien taxa in terms of the magnitude of their deleterious environmental impacts in invaded areas, termed EICAT (Environmental Impact Classification for Alien Taxa). EICAT is receiving increasing international support and has recently been adopted by the IUCN (https://www.iucn.org/theme/species/our-work/invasive-species/eicat); however it does not include socio-economic impacts. Even though environmental impacts are the stated priority in the EU IAS Regulation (EU, 2014), socio-economic impacts are also addressed and can often be even more readily apparent and of immediate concern to stakeholders, especially in the case of alien species that pose health hazards or act as pests (Vilà *et al*., 2010; Kumschick *et al*., 2015). Efforts to quantify socio-economic impacts in monetary terms have indicated that cost figures may help spur politicians/managers into action, engage the public and strengthen support for policy measures (Scalera, 2010) but may not always be a reliable measure of harm or risk to human well-being (e.g. consider impacts on health and on sectors that employ people close to the poverty limit) (Bacher *et al*., 2018). Moreover, monetary costs remain rather scarce and unevenly distributed across species, regions and human activities (Kettunen *et al*., 2008), such economi that assessment and prioritization on the basis of economic measures alone is unlikely to represent the full range of socio-economic impacts of alien species. Recently, Bacher *et al*. (2018) developed a tool structurally similar to EICAT, specifically addressing socio-economic impacts, termed SEICAT (Socio-Economic Impact Classification of Alien Taxa). The novelty of SEICAT is that, rather than using monetary costs, it examines alien species' impacts on human well-being, employing the capability approach from welfare economics (Sen 1999; Robeyns 2005; 2011). The term human well-being, as used in socio-economic research, developed from the work of Narayan *et al*. (2000), documenting the perceptions and realities of the lives of people around the world and their ideas about what constitutes bad and good life (see also MEA, 2003). Human well-being encompasses the fundamental qualities and conditions that are necessary for a decent and fulfilling life. These are summarised in four constituents, namely material and immaterial assets, security, health and good social relations, underpinned by freedom of choice and action (Narayan *et al*., 2000). The capability approach argues that rather than income or other resources available to people, it is the capabilities or opportunities they are presented with, i.e. what they can be and do in their lives, that constitute human well-being (Sen, 1999; Polischuk & Rauschmayer, 2012). To the extent that alien species can change the environmental factors, economic setting and even the social context that determine people's potential capability set, they can affect human well-being through changes in one or more of its constituents.

In this context, SEICAT uses changes in peoples' activities (i.e. realised opportunities) as a common metric for evaluating impacts on well-being (Bacher *et al*., 2018), facilitating comparisons between different taxonomic groups, ecosystems and socio-economic environments and capturing context dependence. EICAT and SEICAT are designed to complement each other as they share similar key properties. They both assess only documented impacts, they address only deleterious effects and they classify alien species based on the maximum documented magnitude of their impacts into the same five ranked levels of impact from "Minimal Concern" to "Massive", where impacts are irreversible even after eradicating the alien population (Blackburn *et al*., 2014; Bacher *et al*., 2018).

EICAT has been already applied to alien bird species

(Evans *et al*., 2016), reptiles and amphibians (Kraus, 2015; Kumschick *et al*., 2017), grasses (Visser *et al*., 2017) and two species of parrots (Turbé *et al*., 2017), whereas, being a more recent protocol, SEICAT has only been applied to amphibians (Bacher *et al*., 2018). In the future, SEICAT and EICAT should be applied to all alien populations to collate data that can underpin prioritization and advance our understanding of the context-dependence of impacts. Here, we focus on seven Lessepsian fishes with reported impacts in the Mediterranean Sea, which we assess with SEICAT and EICAT. This allows a more transparent and comprehensive assessment of negative impacts in the focal area of interest to explore possible links between environmental and socio-economic impacts. We provide an up-to-date systematic literature review of the impacts of the selected species, highlighting gaps in our knowledge and areas where further research is urgently needed.

Methods

Choice of species

In the Eastern Mediterranean Sea, the dominant pathway of introduction of marine non-native species is the Suez Canal (Essl *et al*., 2015), whereby species of Indo Pacific origin find access to the Mediterranean waters (Lessepsian immigrants). Indeed, the Levantine Sea, as a hot spot for Lessepsian immigrants, is the first region where their dispersal, interactions with the native ecological communities but also with the human element are manifested and most likely also documented. Currently there are approximately 153 alien marine fishes in the Mediterranean (HCMR, offline database); 2/3 of Indo-Pacific origin (102 species: Fricke *et al*., 2017). In a recent meeting (September 2017), a Joint GFCM-UN Environment/MAP working group identified 7 of these species as priority fish alien species for monitoring in the Eastern Mediterranean in relation to fisheries (UNEP/MAP, 2017). These species are: *Saurida lessepsianus* Russell, Golani, Tikochinski, 2015 [until recently misidentified as *S. undosquamis* (Richardson, 1848)]; *Fistularia commersonii* Rüppell, 1838; *Lagocephalus sceleratus* (Gmelin, 1789); *Plotosus lineatus* (Thunberg, 1787); *Siganus rivulatus* Forsskål & Niebuhr, 1775 and *Siganus luridus* (Rüppell, 1829) (treated here as one taxonomic unit *Siganus* spp.); and *Pterois miles* (Bennett, 1828). All 7 species are also included in a recently compiled list of invasive/potential invasive alien species in the East and South European Network for Invasive Alien Species (ESENIAS) countries (Karachle *et al*., 2017). All species entered the Mediterranean between 1027 and 2003; for the first 6, impacts in the region have been, to varying extents, reported (see also review by Katsanevakis *et al*., 2014 for European waters); as such they were assessed for the Eastern Mediterranean as the focal region (see *Assessment Protocols* - *Scoring and reporting* for terminology and definitions). *Pterois miles*, a recent invader through the Suez Canal (Bariche *et al*., 2013), is spreading fast in the Mediterranean and is already attaining substantial densities (Jimenez *et al*., 2016; Kletou *et al*., 2016), even though impacts have not been reported yet. However, based on its invasion history in the Gulf of Mexico and the Caribbean, as well as the severity of the documented impacts there, it has raised significant concerns among scientists (e.g. Bariche *et al*., 2013; Jimenez *et al*., 2017) and is already the subject of dedicated research (see project RELIONMED-LIFE: Preventing a lionfish invasion in the Mediterranean through early response and targeted removal (LIFE16 NAT/CY/000832)) and EU wide risk-assessment. For *P. miles*, we applied SEICAT and EICAT with the western Atlantic as the focal region. In that region, the morphologically similar but genetically distinct (Freshwater *et al*., 2009) *P. miles* and *P. volitans* appear together and are not always distinguished in studies, they were thus treated as one taxon for the assessment.

Literature search

The literature search for species impacts followed the principles outlined in Evans *et al*. (2016). Literature up to October 2017 was searched using each species' scientific name in Web of Science, Google Scholar and Google, and scanned for reported impacts. The search was constrained by the introduction year in the area of interest for each species. Web of Science results were first searched exhaustively, while in Google Scholar only the first 200 reports were searched. Additional search strings were used; "Lessepsian" AND "immigrant" OR "fish" AND "Mediterranean", "Pterois" OR "lionfish" OR "Plotosus lineatus" AND "envenomation" OR "injury", "Lagocephalus sceleratus" OR "pufferfish" OR "poisoning". Other online resources searched included Delivering Alien Invasive Species Inventories for Europe (DASIE) (http://www.europe-aliens.org), CABI's Invasive Species Compendium (http://www.cabi.org/isc/) and the Global Invasive Species Database (GISD) of the Invasive Species Specialist Group (ISSG) (http://www.issg.org/database/welcome/). Key publications on marine invasions in the Mediterranean were used as a starting point for the assessment process, including Streftaris & Zenetos (2006), Otero *et al*. (2013), Katsanevakis *et al*. (2014). Relevant references listed in this first set of publications were consulted and included when appropriate, as was grey literature, if it was accessible. Furthermore, national experts in the affected countries were contacted in search of newspaper articles reporting impacts of the selected species. Even though the search in the electronic press was not strictly systematic or exhaustive and we are aware of the biases it may introduce, the aim was to collect as many reports as possible for the database which is meant to be improved in the future with recurring assessments. For each reported impact an entry was made in a spreadsheet with the direct citation from the published text and the source (when text was added for clarification purposes it was entered in parentheses) and was scored according to the protocols described below. These entries are henceforth referred to as impact records. Only primary literature, i.e. reporting direct observations of impacts, was used to extract impact records for the assessment spreadsheet. Review articles, although not recommended as sources of information according to the application criteria of the two protocols, were used in a limited number of cases where the synthesis of the available information led to a novel conclusion or where previously unreported information was presented. Injuries to aquarists were not included in our database because they do not result from alien species populations in the wild. Moreover, we did not consider any positive impacts since these are not currently assessed by the protocols.

Assessment Protocols

EICAT is described in detail in Blackburn *et al*. (2014) and Hawkins *et al*. (2015) while SEICAT is presented in Bacher *et al*. (2018); here we only give a brief description of the concepts and procedures.

Classification scale: EICAT and SEICAT classify alien species according to the magnitude of their environmental and socio-economic impacts respectively into 5 ranked classes, ranging from Minimal Concern to Massive, each level representing more severe impacts (see Table 1 for a summarised version). IN EICAT the assessment units are the native species; thus, each category describes impacts at increasing biological organisation levels; starting from impacts on individual fitness and culminating with irreversible changes at the ecosystem level due to irreversible local species extinction(s). It is important to clarify here that in the EICAT framework, changes in the abundances of native species do not qualify as community changes under the Major impacts scenario (MR); these occur when (at least) one population of a native species goes locally extinct (i.e. at the typical spatial scale at which original native communities can be characterised - Blackburn *et al*., 2014). In SEICAT, the assessment units are the realised human activities, i.e. the subset of activities the social communities in the region of interest actually engage in. The magnitude of change is measured primarily on the basis of how people are affected in their normal activities (i.e. have difficulties or stop participating in an activity), each category representing more severe impacts, manifested across a larger group of people. The irreversible loss of an activity from a local community is considered a Massive impact.

Mechanisms of change: EICAT considers 12 mechanisms under which alien taxa can affect the recipient species and communities: (1) competition; (2) predation; (3) hybridization; (4) transmission of diseases to native taxa; (5) parasitism; (6) poisoning/toxicity; (7) bio-fouling; (8) grazing/herbivory/ browsing; (9) chemical; (10) physical or (11) structural impact on ecosystem; (12) interaction with other alien species. Each taxon is assessed for its impacts under all possible mechanisms for which information is available. The structural equivalents of these mechanisms in SEICAT are the constituents of human well-being. Changes in an activity can result from impacts on more than one constituent of well-being and, conversely, impacts on one component of human well-being may affect more than one activity. As an example, injuries from a venomous fish species can affect a

Table 1. Summary of EICAT and SEICAT impact categories with brief description of the severity of impacts (adapted from Blackburn *et al.,* 2014 and Bacher *et al.,* 2018).

	Massive (MV)	Major (MR)	Moderate (MO)	Minor (MN)	Minimal concern (MC)
EICAT	Causes at least local extinction of native species, and irreversible changes in community composition; even if the alien taxon is removed the system does not recover its original state	Causes at least local extinction of native species and thus changes in community composition, which are reversible if the alien taxon is removed	Causes population declines in native species, but no changes in community composition due to local extinction of one or more native species	Causes reductions in individual fitness, but no declines in native population sizes.	No effect on fitness of individuals of native species
SEICAT	Local disappearance of an activity from a local community, irreversible for at least a decade ("regime shift")	Local disappearance of an activity from at least part of the area invaded by the alien taxon, likely to be reversible within a decade after removal or control of the alien taxon	Changes in activity size, fewer people participating in an activity, but the activity is still carried out	Difficult for people to participate in their normal activities, but no changes in activity size	Unlikely to have caused deleterious impacts on individual people's wellbeing

wide variety of activities; on one hand commercial fishing but on the other hand also recreational uses of the sea. However, commercial fishing can change due to impacts on different constituents of well-being, namely through health risks to fishers and a decline in target species populations or damages to fishing gear (material assets). In defining activities, we were guided by the nature of the impact of the alien taxa (Bacher *et al*., 2018; see also Roy *et al*., 2017a, Supplementary Table 3 for a suggested check list). Health impacts that are not specifically connected to a particular activity (e.g. stings from venomous species during fishing) but impede all aspects of life were assessed as affecting multiple activities; in our study this pertains to poisoning incidents caused by the consumption of *L. sceleratus*.

Scoring and reporting: Both classifications are based on the best available evidence; i.e. only documented impacts are scored, each record being assessed separately. *S. lessepsianus, L. sceleratus, F. commersonii, P. lineatus, S. rivulatus* and *S. luridus* were assessed for the Eastern Mediterranean as the "focal region", i.e. the region in which the alien taxon is having its maximum recorded impacts and is used to inform the assessment (Hawkins *et al*., 2015). None of these 6 species have alien populations anywhere else other than the Mediterranean Sea, so that the current assessments can be considered as global. The assessment of *P. miles/volitans* is also global but uses impact data from the Western Atlantic as the focal region. This reflects the precautionary principle for alien impacts, however caution is advised when interpreting or transferring impact classifications to areas outside the focal region as impact listings are likely to be context-dependent: an alien impact that is observed in one area of the introduced range may not occur or may not be as important elsewhere (Bacher *et al*., 2018). Each score is accompanied by a confidence level and the appropriate justification. Confidence ratings were assigned according to Hawkins *et al*. (2015) and Bacher *et al*. (2018) - three scores of high, medium and low based on the strength of evidence, spatial scale of the reported impact, quality and consistency of the data/information, and the ease of interpretation. The final impact score is the maximum score ever achieved in history, both at the temporal and at the geographic level, and acts as a proxy of the potential maximum impact the species can achieve in the absence of management. The final confidence level of the species assessment corresponds to the highest confidence accompanying the highest impact scored records. Where insufficient data were available to determine and classify impacts of an alien species, it was assigned as data deficient (DD).

Quality control: All assessments were independently cross-checked for consistency by a colleague experienced in S/EICAT assessments (Lara Volery, University of Fribourg), and who is not a co-author. The final scores were agreed by consensus among all authors.

Results

Overall scoring

For socio-economic impacts, overall 39 publications and 9 electronic media sources yielded 65 records entered into the SEICAT scoring sheet (Supplementary Material). Of these, 41 were scored with one of the five ranked classes, 5 were assigned as Data Deficient and 19 did not constitute impact reports according to the SEICAT criteria; records from the two latter groups are still included in the data base to clarify context. The activities affected by the 7 examined marine fish species were commercial fishing (≈50% of the scored records), recreational fishing (angling, spearfishing), other recreational uses of the sea (going to the beach/swimming in the sea), commercial diving and multiple activities affected due to poisoning or envenomation (Fig. 1A). With respect to the constituents of human well-being, impacts were demonstrated more commonly on health and material assets. All the examined species interfered to varying extents with commercial fishing, while only one species, *L. sceleratus*, affected all the constituents of human well-being (Fig. 1B). The highest score assigned was MO (Moderate), related exclusively to records demonstrating the effects of *L. sceleratus* on human health (n=6). All other impact records were either MC (Minimal Concern), MN (Minor) (Fig. 2) or DD as they lacked sufficient documentation. Confidence levels were medium (61% of records) to low (32%), generally reflecting an unclear description of impact magnitude (i.e. according to the SEICAT criteria).

With respect to environmental impacts, 29 publications yielded 35 records for the database, of which 27 were scored with one of the five EICAT impact classes, 2 were assigned to the DD category and 6 remained unscored as they did not fulfil the criteria for impact description (Supplementary Material). The environmental impact records were generally more straightforward and easier to interpret than socio-economic, reflected in the lower percentage of unscored records. The confidence level of the assessments (74 % medium, 18.5 % low) was more often associated with the scale at which impacts were manifested rather than with uncertainties about the magnitude of impacts *per se*. This is largely due to the dominance in the impact reports of small-scale field experiments on the predation effects of *Pterois miles/volitans*. Impact scores ranged from Minimal Concern (MC) to Major (MR) (Fig. 2) but two out of the seven examined species lacked sufficiently strong evidence to be assigned an impact score according to EICAT and were assigned to the DD category (Table 2). The environmental impact mechanisms identified for alien marine fishes were, in ranking order, predation, competition and grazing/herbivory (Fig. 1C). The highest score assigned (MR) was associated with 4 records describing the disappearance of native species, 2 representing predation effects of *P. miles* (local extinc-

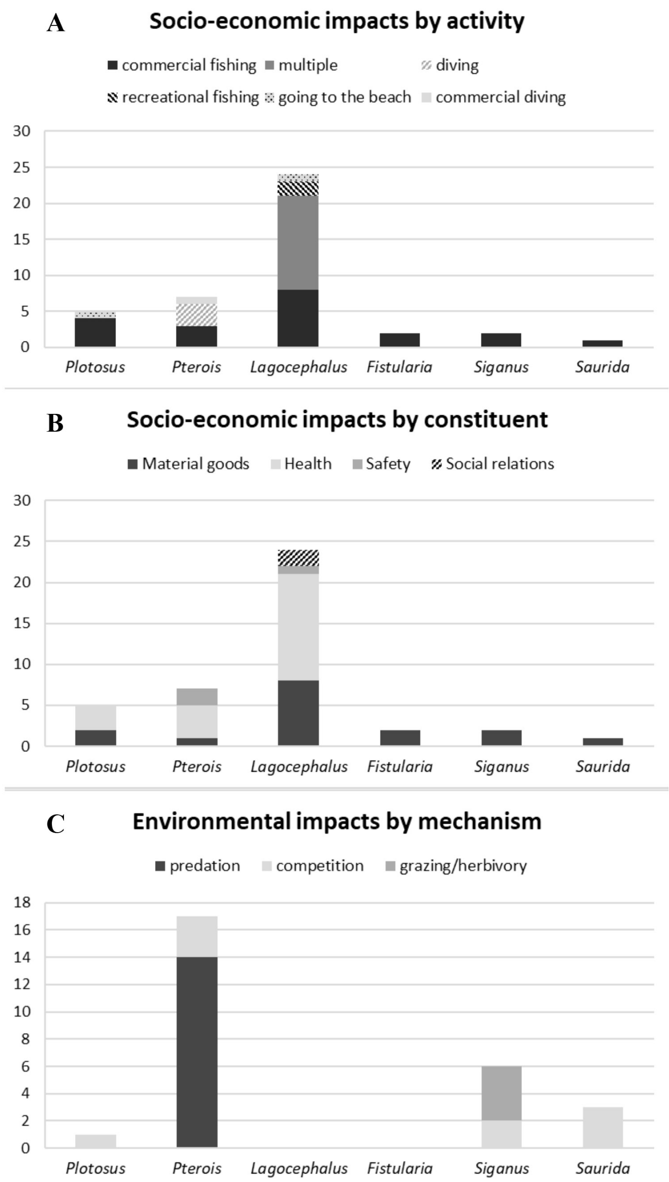

Fig. 1: Distribution of socio-economic impact records of selected invasive fishes by human activity (A-top) and constituent of well-being (B-middle) and of environmental impacts by mechanism for which information was available (C-bottom).

Table 2. Summary of results of the environmental (EICAT) and socio-economic (SEICAT) impact assessment of the selected marine invasive fish taxa. Abbreviations for impact classes: MN - Minor, MO - Moderate, MR - Major, DD - Data Deficient. Focal Area: the region in which the alien taxon is being assessed.

	EICAT	Confidence	SEICAT	Confidence	Focal Area
Plotosus lineatus	MO	low	MN	medium	Eastern Mediterranean
Pterois miles/volitans	MR	medium	MN	medium	Western Atlantic
Lagocephalus sceleratus	DD		MO	medium	Eastern Mediterranean
Fistularia commersonii	DD		MN	low	Eastern Mediterranean
Siganus spp.	MR	high	MN	medium	Eastern Mediterranean
Saurida lessepsianus	MO	low	MN	low	Eastern Mediterranean

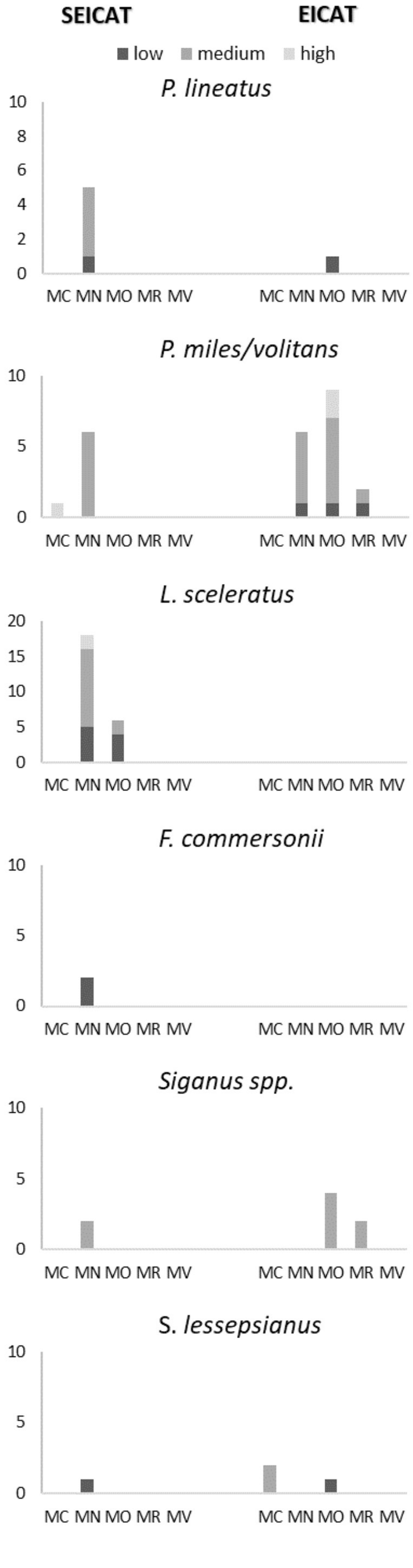

Fig. 2: Distribution of socio-economic (SEICAT) and environmental (EICAT) scores for impact records of selected invasive fish species in the Mediterranean (except for *Pterois miles/volitans* - see text). Abbreviations for impact classes: MC - Minimal Concern, MN - Minor, MO - Moderate, MR - Major, MV - Massive.

tion of native herbivorous fish species) and 2 representing grazing/herbivory impacts by *Siganus* spp. on *Cystoseira* forests (local extinction of *Cystoseira* spp.). For the 4 taxa for which both assessments were available (Table 2), EICAT scores were always higher than SEICAT scores and there was no correlation between environmental and socio-economic impacts.

Species assessments

In this section, summaries of the main impacts per protocol are presented for each species. These are better understood with reference to the detailed scoring spreadsheet for all individual impacts reports provided as Supplementary Material.

Plotosus lineatus (striped eel catfish)

First reported in the Mediterranean by Golani (2002), *P. lineatus* established itself all along the Israeli coast, becoming a dominant member of the ichthyofauna and subsequently of trawl catches (Edelist *et al*., 2012), and was recently detected in Syrian (Ali *et al*., 2015), south-eastern Turkish waters (Doğdu *et al*., 2016) and Tunisia (Ounifi-Ben Amor *et al*., 2016). A venomous alien species, its sting can cause painful injuries, sometimes accompanied by hypertension and tachycardia and a risk of secondary infection (Bentur *et al*., 2017).

We classified the socio-economic impacts of *P. lineatus* as MN according to SEICAT through its effects on several constituents on human well-being. The species interferes with both commercial and, to a lesser extent, recreational fisheries, but we found no indication that the magnitude of these activities has decreased. The high discard rates of this species in commercial trawl catches (Edelist *et al*., 2012) were associated with an increase in the time required to sort the catch, as *P. lineatus* is highly venomous and extra care is needed for its handling (Dor Edelist, University of Haifa/Israel Oceanographic and Limnological Research Institute, personal communication, June 2017). As a result, trawl fishers in Israel move to deeper waters occasionally to avoid it (Edelist *et al*., 2012). Edelist *et al*. (2013) surmised that decreased profitability in the trawl fisheries sector in Israel led to a decline of ca. 30% in both the number of trawlers and the overall fishing effort of the fleet (in days at sea/year) between the early 1990s and the late 2000s. However, there is a multitude of reasons that may have contributed to this, from overexploitation to bio-invasion coupled with climate change, damming the Nile, international trade agreements and rising fuel prices (Golani *et al*., 2017), such that attributing decrease in activity size to any one reason or any one of the invasive species that increase discard rates would be unfounded without any additional data or analysis. With regards to recreational uses of the sea (beach-going and recreational fishing), there have been a number of injuries (Bentur *et al*., 2017; Gweta *et al*., 2008) but no evidence to suggest that people are deterred from carrying out these activities in the impacted areas due to the presence of *P. lineatus*. As for environmental impacts, we scored according to EICAT *P. lineatus* as MO, due to its putative displacement of the native weaver-fish *Trachinus draco* (Edelist *et al*., 2012), but the confidence rating of the assessment is low as the evidence for *P. lineatus* as causal agent of the observed population decline is circumstantial and the mechanism (competition) inferred.

Pterois miles/volitans (lionfish, devil firefish)

We scored *P. miles/volitans* as MN in SEICAT due to its interference with spiny lobster fishery and the injuries caused to various groups of stakeholders. Bahamian fishers have claimed that lionfish negatively affect the catch of spiny lobsters (Akins *et al*., 2012), and there is some indication of reduced time spent in shelter potentially affecting the fitness of spiny lobster (Curtis-Quick *et al*., 2013), which is scored in EICAT. However, it is the spiny lobsters that eventually exclude the lionfish from lobster traps, instigating aggression and chasing them away (Lazarre, 2016). There is still a minor impact on the fishery but it results from increased handling times in the presence of lionfish (Henderson, 2012). With respect to health impacts from the sting of the lionfish's venomous spines, lionfish use their venomous spines defensively and will not instigate an attack to humans. Incidents generally occur as a result of careless handling while fishing or preparing food and can be easily avoided by proper safety measures (Resiere *et al*., 2016). Despite the negative publicity on the issue (Carballo-Cardenas, 2015), systematic reports of injuries in the literature are scarce, and they do not indicate a reduction in the size of the affected activities. Impacts on the reef-associated tourism (e.g. diving and snorkelling) may be expected, as suggested by choice experiments examining the recreational and aesthetic value of lionfish-impacted reefs (Malpica-Cruz *et al.*, 2017; van Beukering *et al*., 2014), but these conclusions are based on hypothetical scenarios and do not constitute reported impacts fit to be scored according to the SEICAT protocol. Clearly more rigorous studies are needed to demonstrate such impacts.

Conversely, a wealth of studies - ranging from surveys to field and laboratory experiments - offer ample evidence for the severity of the lionfish invasion environmental impacts. We classified *P.miles/volitans* as MR according to EICAT, as it can lead to the local population extirpation of native species (Ingeman, 2016) through predation. However, it may also cause a phase shift towards algal-dominated reefs through local extinction of herbivorous fish species or meso-predator release (Lesser & Slattery, 2011) and non-consumptive effects on herbivorous fish (Kindinger & Albins, 2016). These impacts have been reported at a local scale and can be reversible if algal dominance is supressed by sufficient levels of herbivory (Mumby *et al*., 2007) and, in rare cases, even by regeneration of the remnant coral tissue (Diaz-Pulido *et al*., 2009). It remains to be seen what kind of interactions the lionfish will develop with native species and communities in the Mediterranean and how these will affect human well-being. With particular reference to its interaction with other alien fish species, an interesting line of research would be to examine the potential relationship between the predatory lionfish and the herbivorous *S. luridus* and *S. rivulatus*, which in separate invasion scenarios have had opposite effects on the recipient ecosystems (Bellwood & Goatley, 2017). If *P. miles* preys on the two siganids in the Mediterranean and supresses their populations it may counteract their overgrazing impacts on algal forests. On the other hand, *Fistularia commersonii*, one of the few documented natural predators of *P.miles* (Bernadsky & Goulet, 1991), may exert a measure of population control on the lionfish through predation.

Lagocephalus sceleratus (pufferfish, silver-cheeked toadfish)

Lagocephalus sceleratus is an extremely toxic species which causes severe poisoning that may lead to death when eaten (Bentur *et al*., 2008). Its marketing is prohibited in the EU (EC No 1021/2008) and many non-EU Mediterranean countries have introduced their own restrictions for the fishing, landing and selling of the species, but it is nevertheless still consumed in some countries after the removal of the head and the internal organs (Aydın, 2011; Beköz *et al.*, 2013). It is an aggressive predator that is considered a major nuisance by fishers since it damages fishing gear by attacking fish caught in nets and lines (Nader *et al*., 2012).

Lagocephalus sceleratus can affect human well-being primarily through its impacts on material assets and human health. The species was classified as MO with respect to human health; even though it has been the cause of several deaths by poisoning in Egypt, Lebanon and Syria, its consumption can and should be avoided since its toxicity is well known. Its impacts are therefore comparable to avoiding the consumption of other toxic organisms like e.g. certain mushroom species that also do not induce large changes in societies. However, despite numerous awareness campaigns in Eastern Mediterranean countries (Ben Souissi *et al*., 2014), the information has apparently not reached all those potentially affected and unsuspecting consumers still remain vulnerable (Beköz *et al*., 2013; Ben Souissi *et al*., 2014; Ünal *et al*., 2015; Ünal and Göncüoğlu Bodur, 2017), including tourists and maritime professionals. With respect to commercial fishing (material assets), *L. sceleratus* is classified as MN, since, despite its pest status, there is no evidence to support a reduction or spatial displacement of activity (see Table 1 for a detailed description of impact classes). Similarly, it scores MN for recreational activities (angling, spearfishing, going to the beach) as it disrupts them or induces feelings of fear but these impacts were recorded at a local scale and their description cannot lead to inferences about changes in the size of these activities. We did not find reports of its environmental impacts, and therefore scored it as DD according to EICAT. Being a large and voracious predator with high population densities in the region, *L. sceleratus* is expected to have significant ecological consequences through predation (Kalogirou, 2013; Nader *et al*., 2012) and is considered by local fishers to be responsible for the decline in the populations (and landings) of commercially important native species of cephalopods (EastMed, 2010; Van Ham *et al*., 2013; Panagopoulou *et al*., 2017). However, besides fishers' perceptions and scientists' studies documenting the dietary preference of *L. sceleratus* for cephalopod species in certain areas (Aydın, 2011; Kalogirou, 2013), in our search we found no actual data supporting a decline in cephalopod populations due to predation by *L. sceleratus*.

Fistularia commersonii (cornetfish)

Fistularia commersonii was first recorded in the Mediterranean in 2000 (Golani 2000) and within 7 years reached the south coast of Spain (Sanchez-Tocino *et al*., 2007). It is considered the fastest (Azurro *et al*., 2013) and farthest spreading Lessepsian immigrant, characterized by rapidly increasing abundance in the invaded areas (Joksimovic *et al*., 2009). A mid-water predator with a dietary preference for commercially important prey species (*Boops boops*, *Engraulis encrasicholus*, *Spicara smaris* and mullids) (Karachle & Stergiou, 2017), it is consistently present in considerable numbers in commercial catches in parts of the invaded range (Southeastern Aegean) (Corsini-Foka & Economidis, 2007).

Fistularia commersonii was assessed as MN for commercial fishing with SEICAT due to its frequent and dominant presence in commercial or experimental catches (Corsini *et al*., 2005; EastMed, 2010; Kalogirou *et al*., 2007). High numbers of non-commercial by-catch species in fishing nets are commonly regarded to negatively affect fishers' income by reducing the amount of commercial species caught (foregone income), increasing handling time of the catch to sort the discards, leading to a reduction in the quality of target species, greater wear and tear of the fishing gear (Clucas, 1997; Streftaris & Zenetos, 2006; Nader *et al*., 2010). It should be noted here that, while *F. commersonii* was discarded throughout the 2010s, it is now locally appreciated at places (e.g., Dodecanese local value of €5-10/kg, Corsini-Foka *et al*., 2017; Cyprus €6-10/kg: N. Michailidis, Department of Fisheries and Marine Research, Cyprus, pers. communication). However, the species was not scored with EICAT for its environmental impacts, i.e. its purported predation effects on the native fish populations. Preference for certain species in the diet of *F. commersonii* does not constitute a documented impact on prey populations, and we found no evidence of population declines of preferred prey species linked to *F. commersonii* predation. This is also true for their commercial catches, in the case of commercially important prey species, even if concerns have been expressed (Corsini-Foka & Economidis, 2007). Thus, the final EICAT score for this species was DD.

Siganus luridus, Siganus rivulatus (dusky spinefoot, parrotfish)

Siganus luridus and *S. rivulatus* entered the Mediterranean in 1956 and 1927 respectively and they have both established important populations in the eastern part of the basin; *S. luridus* is also present in the western Mediterranean, whereas the presence of *S. rivulatus* is suspected as far West as Corsica (Otero *et al*., 2013).

The two siganids were scored MR with EICAT, based on findings that document their dramatic impacts on algal forests through grazing/herbivory. Grazing by *Siganus* spp. creates areas of bare rock with some patches of crustose coralline algae (barrens), devoid of erect macroalgae, namely *Cystoseira* spp. (Sala *et al*., 2011). Sala *et al*. (2011) report that denuded areas stretch for several hundreds of meters at depths of 8-12m (see also Verges *et al*., 2014), while Salomidi *et al*. (2016) observed the complete absence of canopy algae (*Cystoseira*, *Sargassum*) at 6 and 10 out of 18 sampling locations at depths of 5m and 15m respectively. This loss/degradation of habitat causes loss of biodiversity, associated biomass and refugia, reducing the nursery value of the habitat (Cheminée *et al*., 2013). However, since the records for the nursery value of *Cystoseira* forests and the impact of *Siganus* spp. on these habitats come from different sources, the species could not be scored directly for its structural impact on the ecosystem. Being able to combine impact records, which is currently not foreseen in the EICAT/SEICAT protocols but is under development, seems imperative for a better evaluation of the alien taxon. Moreover, there is evidence to suggest that *Siganus* spp. are responsible for the population decline of the native herbivorous fish *Sarpa salpa* (Bariche *et al*., 2004; Giakoumi, 2014), thus they score MO with respect to competition.

When it comes to SEICAT, despite the species' commercial importance in many eastern Mediterranean countries (Shakman & Kinzelbach, 2007; Yemisken *et al*.,2014; Corsini-Foka *et al*., 2017), the siganids were classified as MN for commercial fishing. This was based on findings of high discard rates and avoidance of fishing grounds rich in *Siganus* spp. by fishers in Fournoi Island (Aegean Sea), where there is no market for *Siganus* spp. (Pennington *et al*., 2013) and on complaints by small-scale fishers in Crete (Panagopoulou *et al*., 2017). In fact, *Siganus* spp. has low or no commercial value in most regions of Greece (Tsagarakis *et al*., 2014). On the other hand, socio-economic impacts resulting from the environmental impacts of *Siganus* spp. have not been demonstrated, to our knowledge. In the past the degradation/loss of *Cystoseira* forests due to *Siganus* predation has been assumed to affect a number of ecosystem services, like water purification and carbon storage, life-cycle maintenance, symbolic and aesthetic values, recreation and tourism (Katsanevakis *et al*., 2014), potentially threatening human well-being. However, at the moment, quantifiable links between human activities or constituents of human well-being and the environmental impacts of *Siganus* spp. are lacking.

Saurida lessepsianus (lizzardfish)

Saurida lessepsianus, until recently misidentified and reported as *S. undosquamis*, was first recorded in Israel in 1952 (Ben-Tuvia, 1953). It quickly attained very high densities and constituted a major component of trawl catches in Israel (Ben-Yami & Glaser, 1974), Turkey (Gücü & Bingel, 1994) and Egypt (El-Zarka & Koura, 1965), where it is commercially important. It has since spread throughout the eastern and central Mediterranean, reaching Tunisia (Boughedir *et al*., 2015), the Adriatic (Dulčić *et al*., 2003) and the Aegean (Ondrias, 1971; Ben Tuvia, 1973).

It is reported to have displaced the native and commercially important species European hake (*Merluccius merluccius*) and the Atlantic-Mediterranean lizardfish *Synodus saurus* into deeper waters (Galil *et al*., 2007; Otero *et al*., 2013; Katsanevakis *et al*., 2014), this is however not entirely supported by the primary literature. Both Gücü & Bingel (2011) for Turkey and Ben-Yami & Glaser (1974) for Israel present evidence that it is climatic fluctuations and the movement of cool water masses from the western Mediterranean that are responsible for the population fluctuations of hake in the wild and in fisheries catches. *Saurida lessepsianus* is less sensitive to variations in physical conditions and, consequently exploited the (niche) space made available by the recession/withdrawal of hake. Thus, the reduction in hake populations and catches cannot be unequivocally attributed to *S. lessepsianus,* even though the two species almost certainly compete for food (Ben-Yami & Glaser, 1974). Based on the above, this species was still assigned a MO score for competition according to EICAT, but with a low confidence. With respect to socio-economic impacts, however, the SEICAT score on commercial fisheries will essentially depend on the relative value of the two species in the market, since *S. lessepsianus* soon became and still is a commercial species in some Eastern Mediterranean countries. Based on current prices in Turkey (http://eislem.izmir.bel.tr/balikhalfiyatlari.aspx) and Israel (N. Stern, Israel Oceanographic and Limnological Research Institute, pers.comm.), hake is at least 2-3 times more expensive than *S. lessepsianus*, the latter species was thus assigned to the MN class. As for the purported displacement of the native *Synodus saurus* by *S. lessepsianus*, it was contended by Golani (1993), who demonstrated that the bathymetric segregation between the two species "*is not a result of displacement of* Synodus saurus [by Saurida undosquamis] *to shallow water since it was not found in the traditional trawl ground (30-100 m) prior to the invasion of* S. undosquamis". Consequently, the score for this record is MC.

Discussion

This study is one of the first to assess socio-economic impacts of alien species in a systematic way with the new SEICAT protocol. SEICAT and its environmental counterpart, EICAT, offer an objective and transparent way to assess alien species' impacts in the recipient areas based solely on reported/demonstrated impacts. Including all the elements of the assessment in the scoring sheet, most importantly the direct citation from the published text, facilitates the evaluation of the impact assessment by independent reviewers but also offers a solid foundation for the continuous revision of the assessment by highlighting data gaps and giving recommendations for future research (Bacher *et al*., 2018).

Lessepsian alien fishes had higher environmental than socio-economic impacts, similar to freshwater fishes (assessed with the GISS protocol - Kumschick *et al*., 2015) and amphibians assessed with SEICAT/EICAT. They were characterized however by a higher number of socio-economic impact records, confirming previous perceptions that such impacts are more readily perceived and reported by stakeholders (Vilà *et al*., 2010). This is not surprising, given the selection criteria of the seven species and the partial commercial interest some of them already have (*S. lessepsianus*: Egypt, Israel, Turkey; *F. commersonii*: Cyprus, Greece; *Siganus* spp.: Levantine basin) or may have in the future (*P. lineatus* is a commercial species in its native range - Situ & Sadovy, 2004; Vijayakumaran 1997 - *P. miles/volitans* is already consumed in the invaded Atlantic range - Nunez *et al*., 2012).

All selected species interfere with commercial fisheries, either as discards by reducing fishing yield and increasing handling time (especially venomous species such as *P. lineatus* and *P. miles/volitans* but also the two siganids and *F. commersonii*), or by damaging the fishing gear and the fish in the catch (*L. sceleratus*), or lastly by outcompeting and displacing other commercially important species (*S. lessepsianus*). However, these impacts can be variable both in space and in time as some of these species are commercialized in some regions but not in others or are being gradually introduced to the local markets (the case of *Siganus* spp., *S. lessepsianus* and *F. commersonii*). Of particular concern, and with the highest score in SEICAT, are the health impacts caused by the consumption of *L. sceleratus* that is still being consumed either by misinformed or by unsuspecting consumers (Nader *et al*., 2012, Beköz *et al*., 2013, Ben Souissi *et al*., 2014). Additional awareness campaigns are needed, targeting especially vulnerable populations, such as tourists and other travelers and refugees with poor access to information. Finally, recreational uses of the sea are also being affected, either directly through injuries by the venomous *P. lineatus and P. miles/volitans* or indirectly due to fears and concerns about interacting with the alien species, particularly *L. sceleratus*. *P. lineatus*, due to its population explosion and uniform distribution, and *L.*

sceleratus, due to its high densities and rapid dispersal, are causing wide-spread socio-economic impacts in the invaded areas.

In the framework of SEICAT, the examination of the species in this study indicates that, for marine fish, a critical distinction in the classification is between Minor and Moderate impacts; i.e. between an alien species making it difficult for people to carry out their normal activities and actually causing some of them to stop participating in an activity altogether, i.e. inducing changes in the size of the activity. The publications we collected did not offer impact descriptions clear enough to allow this distinction to be made. To strengthen the confidence in our assessments, future socio-economic surveys should be conducted with questionnaires explicitly addressing this difference. A cost-effective way to do that, at least for fishery-related activities, would be to integrate such surveys with existing strategies for an ecosystem-based approach to sustainable fisheries in the Mediterranean (e.g. GCFM mid-term strategy 2017-2020) or, at the EU level, with the Fisheries Data Collection Framework, established with Commission Regulation (EC) No. 665/2008. This way, fisheries' impacts of alien species can be placed in a wider context of the suite of factors that affect the sector and their relative importance can be evaluated accordingly.

Previous approaches have attempted to assess socio-economic impacts of alien species through monetary costs (e.g. Kettunen *et al*., 2009; Williams *et al*., 2010) or by demonstrating, or often assuming, links between environmental impacts and effects on ecosystem services, which in turn are linked to human well-being. Our experience with Lessepsian marine fish species highlights that, among socio-economic impacts, the more immediate and alarming ones are usually disassociated from environmental impacts - notwithstanding that they are both underpinned by high densities of the invading species - and they relate to human health and material assets. Monetary approaches would be able to capture some of these direct impacts, at least those on direct use values (for terminology see Charles & Dukes, 2007). A good example are the studies of Ünal *et al*. (2015) and Ünal & Göncüoğlu Bodur (2017), who investigated the economic losses to small-scale Turkish fisheries caused by *L. sceleratus.* However, these costs are associated with gear loss and labour loss, making them context-dependent and difficult to compare across regions (Bacher *et al*., 2018). Moreover, in the studies we consulted, realized socio-economic impacts were explicitly monetized only in the case of *L. sceleratus*, preventing comparisons across species. Finally, it would be very problematic to ascribe a monetary cost to health impacts, particularly the fatal incidents; similarly, for loss of amenity value relating to safe access to resources (Kelly *et al*., 2013).

Similar to our findings, Katsanevakis *et al*. (2014), reviewing the impacts of marine invasive species on ecosystem services, found that impacts on cultural, regulating and maintenance ecosystem services were based mainly on expert judgment, while direct observations were the most common type of evidence for provisional ecosystem services, that are analogous to the constituent "*material and immaterial assets*". In the present study, even when the information evaluated was drawn from observational data, the confidence assigned to the assessments was low to moderate in the majority of cases. This is understandable when keeping in mind that most reports were conducted without having in mind the classification systems used here. Where competition is implicated in native species' displacements, i.e. for *P. lineatus* and *Siganus* spp., the evidence comes from correlations along temporal or spatial trajectories and it is not always possible to disentangle alien species' impacts from the (synergistic) negative effects of other drivers of change (e.g. overfishing, habitat degradation, climate change, etc.). Laboratory and field experiments investigating niche requirements and competitive interactions between *P. lineatus* and *Trachinus draco* and between *Siganus* spp. and *Sarpa salpa* would help strengthen our inference. Results from laboratory experiments, even though not always accurately reflecting the complex interactions that may develop in natural conditions, can nevertheless aid in the elucidation of proposed impact mechanisms. A characteristic example involves *P. miles/volitans* and the spiny lobster *Panulirus argus*, where laboratory experiments showed that it is the spiny lobster that drives the inverse correlation between the two species in lobster traps and not the other way around (Lazarre, 2016).

In the case of the suspected predation impacts of *F. commersonii* and *L. sceleratus* on commercial fish and cephalopod populations, our understanding is further hampered by the paucity of reliable, long-term fisheries data (Kalogirou, 2013). The predation effects of *P. miles*, a demersal, highly territorial and relatively static species, were largely demonstrated with manipulative field experiments (e.g. Albins, 2015; Green *et al*., 2012, 2014, Benkwitt 2015; Ingeman, 2016, see Supplementary material for a full list); however large and highly mobile predators are rarely amenable to such manipulations (Kalogirou *et al*., 2007). A possible way to tackle this is to set up carefully designed monitoring programs in new areas of expansion of these species and track the development of the populations of predators *vs*. their preferred prey. Alongside simultaneous recording of relevant environmental and anthropogenic pressure indicator data, this new information could help us make stronger inferences. Additional insights can be gained by ecosystem modelling that includes fisheries catches with a mass balance model such as Ecopath with Ecosim (Christensen & Walters 2004), especially in regions for which such models have been developed in the past (e.g. North Aegean, Tsagarakis *et al*., 2010). This approach was exemplified by Pinnegar *et al*. (2014), who simulated altered food-webs under different scenarios of *F. commersonii* densities in Corsica and by Bumbeer *et al*. (2017) conducting a similar exercise for *Pterois volitans* in Brazil.

Our review indicated that socio-economic impacts resulting from high level ecological impacts (habitat degradation/loss, ecosystem modification/loss of function) are not readily explored or easily demonstrated, at least not within timeframes that are conducive to timely and effective management (e.g. see Booy *et al*. (2017) for suggested timeframes for the management of some marine IAS). Moreover, since there is often a substantial delay between the introduction of an alien species and the realization/detection of indirect impacts (Rabitsch *et al*., 2016), a combination of results from multiple studies may be required to demonstrate impacts (e.g. the consequences of *Cystoseira* forests loss from *Siganus* spp. grazing). There are currently no clear guidelines in the EICAT/SEICAT framework on how to classify impact magnitude and confidence from multiple studies, but work is under way to devise an objective scheme that allows the combination of impact records. Another obstacle is the paucity of studies directly addressing alien species' impacts on cultural aspects of ecosystems, such as their recreational, aesthetic/symbolic and other non-use values. Choice experiments, like the ones conducted by van Beukering *et al*. (2014) and Malpica-Cruz *et al*. (2017) in relation to *P. volitans*, may offer useful insights with regard to conservation and management initiatives, the hypothetical scenarios they present though may not come to pass such that their results do not constitute admissible evidence for impact assessment. Clearly, stronger evidence from specifically focused studies is needed to demonstrate indirect socio-economic impacts on all constituents of human well-being. For example, a study could be designed that directly investigates the impact of the barrens created by *Siganus* spp. on the recreational and aesthetic value of *Cystoseira* forests e.g. by involving divers at the affected locations. Similarly, the potential impacts of lionfish on the reef-associated tourism industry could be examined along real spatial and temporal gradients of habitat degradation or native species richness/density. Such case studies could also provide a platform for the testing of novel, subjective well-being indicators which were recently developed for the marine environment (Bryce *et al*., 2016) within the context of a new conceptual framework for cultural ecosystem services (Fish *et al*., 2016b). This new approach defines cultural ecosystem services as the interaction between environmental spaces and the cultural practices that take place within them and offers a method to integrate the tangible and intangible cultural goods and benefits that enable and are shaped by this interaction (Fish *et al*., 2016b). Applications in the marine (Bryce *et al*., 2016) and the terrestrial (Fish *et al*., 2016a) environment show promise for quantitative ecological knowledge production relevant for prioritisation and decision-making.

Nevertheless, regardless of conceptual and methodological approaches, there are cultural attributes of species, habitats and ecosystem that are difficult to fit into well-defined human activities and thus, impacts on some constituents of human well-being remain poorly quantified and evaluated. For example, people may not engage e.g. in recreational activities or specific conservation efforts related to an impacted habitat, but may still derive satisfaction from the knowledge it exists (Loomis & White, 1996), feel a strong social/symbolic connection to it (linked to identity, sense of place and belonging - Russell *et al*., 2013) or the moral imperative to preserve it for future generations. Such difficulties are not specific to the SEICAT method; for example, impacts on existence, bequest and spiritual values receive little attention in the highly-economised western cultures (La Rosa *et al*., 2016), are notoriously difficult to monetize in the economic valuation of ecosystem services approach (Charles & Dukes, 2007; Kelly *et al*., 2013) and arguably require a plurality of discourses that incorporates not only the uni-directional thinking of nature in service to humans but also concepts of reciprocity and the stewardship of nature (Cooper *et al*., 2016). A further discussion of these topics is beyond the scope of the present study but a growing body of literature can help researchers design new approaches to begin addressing them.

To conclude, with the existing ecological knowledge, a straightforward approach that directly considers impacts on human activities is needed for demonstrating impacts and contributing to the overall evaluation of the deleterious effects of alien species in the framework of evidence-based decision-making. From a management perspective, the SEICAT/EICAT framework can be very valuable at the hazard identification and risk assessment phases of risk analysis (Booy *et al*., 2017; Vanderhoeven *et al*., 2017), whereby the species that pose the highest risks are identified along with the certainty with which we can attribute cause and effect and priority areas for research. In this sense, our application of SEICAT/EICAT can serve as a new baseline for the current state of knowledge of the 7 examined alien fish species, to be updated as new information emerges. *Lagocephalus sceleratus* was demonstrated as the species with the highest socio-economic impact and the highest number of impact reports, followed by *Plotosus lineatus* in the Mediterranean and *Pterois miles/volitans* in the Western Atlantic. The latter two species, being more recent invaders in the Mediterranean, with still limited distribution (*P. lineatus*) and/or population densities (*P. miles*) have already been selected for EU-wide risk assessment (projects ENV.B2.ETU/2017/0013 and LIFE16 NAT/CY/000832 respectively), partly on the rationale that recent invasions present a higher potential for more timely and effective intervention and management (Roy *et al*., 2015). There is however a clear need for a formal risk assessment of *L. sceleratus*, including assessment of potential management measures, at least in the Mediterranean Sea, if not all European Seas. Our analysis indicates that there are significant data gaps regarding its environmental impacts which urgently need to be addressed to better inform risk-assessment, while socio-economic impacts could be better assessed with more detailed information on the magnitude of impacts for all the examined species. Considering that the 5-level impact classification scale developed in EICAT/SEICAT is also adopted within the new Risk Assessment template employed by the European Commission for public consultation and prioritization, (Roy *et al*., 2017b), specifically adapted questionnaires as described above would be particularly informative.

Acknowledgements

This study was the result of a COST Action STSM grant to M.G., hosted by A.Z. and supported by S.B, within the project "Alien Challenge - COST TD1209". The authors wish to thank Lara Volery (University of Fribourg) for independently evaluating all EICAT/SEICAT scores. A.Z. was partially supported by the "MEDCIS" project (Support Mediterranean Member States towards coherent and Coordinated Implementation) of the second phase of the MSFD No. 11.0661/2016/748067/SUB/ENV.C2. Can Bizsel and Şükrü Beşiktepe are cordially thanked for providing administrative support for the STSM action. Finally, we are grateful to the two reviewers, whose helpful comments helped improve the quality of this manuscript.

References

Akins, L., Lazarre, D., Die, D., Morris, J., 2012. Lionfish By-catch in The Florida Lobster Fishery: first Evidence of Occurrence and Impacts. In *Proceedings of the Gulf and Caribbean Fisheries Institute* Vol. 65, pp. 329-330.

Albins, M.A., 2015. Invasive Pacific lionfish *Pterois volitans* reduce abundance and species richness of native Bahamian coral-reef fishes. *Marine Ecology Progress Series*, 522, 231-243.

Ali, M., Saad, A., Soliman, A., 2015. Expansion confirmation of the Indo-Pacific catfish, *Plotosus lineatus* (Thunberg, 1787), (Siluriformes: Plotosidae) into Syrian marine waters. *American Journal of Biology and Life Sciences*, 3 (1), 7-11.

Aydın, M., 2011. Growth, Reproduction and Diet of Pufferfish (*Lagocephalus sceleratus* Gmelin, 1789) from Turkey's Mediterranean Sea Coast. *Turkish Journal of Fisheries and Aquatic Sciences,* 11, 569-576.

Azzurro, E., Soto, S., Garofalo, G., Maynou, F., 2013. *Fistularia commersonii* in the Mediterranean Sea: invasion history and distribution modeling based on presence-only records. *Biological Invasions*, 15 (5), 977-990.

Bacher, S., Blackburn, T.M., Essl, F., Genovesi, P., Heikkilä, J. *et al*., 2018. Socio-economic impact classification of alien taxa (SEICAT). *Methods in Ecology and Evolution*. 9, 159-168.

Bariche, M., Alwan, N., El-Assi, H., Zurayk, R., 2009. Diet composition of the Lessepsian bluespotted cornetfish *Fistularia commersonii* in the eastern Mediterranean. *Journal of Applied Ichthyology*, 25 (4), 460-465.

Bariche, M., Letourneur, Y., Harmelin-Vivien, M., 2004. Temporal fluctuations and settlement patterns of native and Lessepsian herbivorous fishes on the Lebanese coast (eastern Mediterranean). *Environmental Biology of fishes*, 70 (1), 81-90.

Bariche, M., Torres, M., Azzurro, E., 2013. The presence of the invasive lionfish *Pterois miles* in the Mediterranean Sea. *Mediterranean Marine Science*, 14 (2), 292-294.

Beköz, A. B., Beköz, S., Yilmaz, E., Tüzün, S., Beköz, U., 2013. Consequences of the increasing prevalence of the poisonous Lagocephalus sceleratus in southern Turkey. *Emergency Medical Journal*, 30, 954-9555.

Bellwood, D.R., Goatley, C.H.R., 2017. Can biological invasions save Caribbean coral reefs? *Current Biology*, 27 (1), R13-R14.

Ben Souissi, J., Rifi, M., Ghanem, R., Ghozzi, L., Boughedir, W. *et al.,* 2014. *Lagocephalus sceleratus* (Gmelin, 1789) expands through the African coasts towards the Western Mediterranean Sea: a call for awareness. *Management of Biological Invasions,* 5, 357-362.

Ben-Tuvia, A., 1953. New Erythrean fishes from the Mediterranean coast of Israel. *Nature*, *172* (4375), 464-465.

Ben-Tuvia, A., 1973. Man-made changes in the eastern Mediterranean Sea and their effect on the fishery resources. *Marine Biology*, 19 (3), 197-203.

Benkwitt, C.E., 2015. Non-linear effects of invasive lionfish density on native coral-reef fish communities. *Biological Invasions*, 17 (5), 1383-1395.

Bentur, Y., Altunin, S., Levdov, I., Golani, D., Spanier, E. *et al*., 2017. The clinical effects of the venomous Lessepsian migrant fish *Plotosus lineatus* (Thunberg, 1787) in the Southeastern Mediterranean Sea. *Clinical Toxicology*, 1-5.

Ben-Yami, M., Glaser, T., 1974. The invasion of *Saurida undosquamis* (Richardson) into the Levant basin - An example of biological effect of interoceanic canals. *Fishery Bulletin*, 72, 359-373.

Bernadsky, G., Goulet, D., 1991. A natural predator of the lion-fish, *Pterois miles*. *Copeia*, (1), 230-231.

BIO Intelligence Service, 2011. *A comparative Assessment of existing policies on invasive species in the EU Member States and in selected OECD countries.* Final report for the European Commission. DG ENV, 258 pp.

Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P. Jarošík, V. *et al*., 2011. A proposed unified framework for biological invasions. *Trends in Ecology and Evolution,* 26, 333-339.

Blackburn, T. M., Essl, F., Evans, T., Hulme, P. E., Jeschke, J. M. *et al*., 2014. A Unified Classification of Alien Species Based on the Magnitude of their Environmental Impacts. *PLoS Biology*, 12(5): e1001850. https://doi.org/10.1371/journal.pbio.1001850.

Booy, O., Mill, A. C., Roy, H. E., Hiley, A., Moore, N. *et al*., 2017. Risk management to prioritise the eradication of new and emerging invasive non-native species. *Biological Invasions*, 19 (8), 2401-2417.

Boughedir, W., Rifi, M., Shakman, E., Maynou, F., Ghanem, R. *et al*., 2015. Tracking the invasion of *Hemiramphus far* and *Saurida undosquamis* along the southern Mediterranean coasts: a local ecological knowledge study. *Mediterranean Marine Science*, 16 (3), 628-635.

Bryce, R., Irvine, K. N., Church, A., Fish, R., Ranger, S. *et al*., 2016. Subjective well-being indicators for large-scale assessment of cultural ecosystem services. *Ecosystem Services*, 21, 258-269.

Bumbeer, J., da Rocha, R. M., Bornatowski, H., de Castro Robert, M., Ainsworth, C., 2017. Predicting impacts of lionfish (*Pterois volitans*) invasion in a coastal ecosystem of southern Brazil. Biological Invasions, 1-18. https://doi.org/10.1007/s10530-017-1625-8

Carballo-Cardenas, E. C., 2015. Controversies and consensus on the lionfish invasion in the Western Atlantic Ocean. *Ecology and Society,* 20 (3), 20 . doi:10.5751/ES-07726-200324.

Charles, H., Dukes, J. S., 2007. Impacts of Invasive Species on Ecosystem Services in: *Biological Invasions*, ed. W. Nentwig (Berlin, Heidelberg: Springer-Verlag).

Cheminée, A., Sala, E., Pastor, J., Bodilis, P., Thiriet, P. *et al*., 2013. Nursery value of Cystoseira forests for Mediterranean rocky reef fishes. *Journal of Experimental Marine Biology*

and Ecology, 442, 70-79.
Christensen, V., Walters, C. J., 2004. Ecopath with Ecosim: methods, capabilities and limitations. *Ecological modelling*, 172 (2), 109-139.
Clucas, I., 1997. *A study of the options for utilization of bycatch and discards from marine capture fisheries*. FAO Fisheries Circular. No. 928. Rome, FAO. 1997. 59p.
Cooper, N., Brady, E., Steen, H., Bryce, R., 2016. Aesthetic and spiritual values of ecosystems: recognising the ontological and axiological plurality of cultural ecosystem 'services'. *Ecosystem Services*, 21, 218-229.
Copp, G., Vilizzi, L., Tidbury, H., Stebbing, P., Tarkan, A. S., Miossec, L. *et al*., 2016. Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. *Management of Biological Invasions, 7*, 343-350.
Corsini, M., Margies, P., Kondilatos, G., Economidis, P., 2005. Lessepsian migration of fishes to the Aegean Sea: First record of *Tylerius spinosissimus* (Tetraodontidae) from the Mediterranean, and six more fish records. *Cybium,* 29, 347-354.
Corsini-Foka, M., Economidis, P. S., 2007. Allochthonous and vagrant ichthyofauna in Hellenic marine and estuarine waters. *Mediterranean Marine Science*, 8 (1), 67-90.
Corsini-Foka, M., Mastis, S., Kondylatos, G., Batjakas, I. E., 2017. Alien and native fish in gill nets at Rhodes, eastern Mediterranean (2014-2015). *Journal of the Marine Biological Association of the United Kingdom,* 97 (3), 635-642.
Curtis-Quick, J., Underwood, E., Green, S., Akins, L. A. D., Harborne, A. *et al*., 2013. Interactions Between the Caribbean Spiny Lobster*, Panulirus argus*, and Invasive Lionfish, *Pterois volitans*: Who Displaces Whom? in *Proceedings of the 66th Gulf and Caribbean Fisheries Institute*, November 4 - 8, 2013 (Corpus Christi, Texas USA).
Diaz-Pulido, G., McCook, L. J., Dove, S., Berkelmans, R., Roff, G. *et al*., 2009. Doom and Boom on a Resilient Reef: Climate Change, Algal Overgrowth and Coral Recovery. *PLoS One*, 4(4), e5239.
Doğdu, S. A., Uyan, A., Uygur, N., Gürlek, M., Ergüden, D. *et al*., 2016. First record of the Indo-Pacific striped eel catfish, *Plotosus lineatus* (Thunberg, 1787) from Turkish marine waters. *Natural and Engineering Sciences*, 1 (2), 25-32.
Dulčić, J., Pallaoro, A., Lipej, L., 2003. Lessepsian Fish Migrants Reported in the Eastern Adriatic Sea: an Annotated List. *Annales. Series historia naturalis*, 13, 137-144.
EastMed, 2010. *Report of the sub-regional technical meeting the lessepsian migration and its impact on eastern Mediterranean fishery*. FAO Nicosia, Cyprus, December, 5-7.
Edelist, D., Golani, D., Rilov, G., Spanier, E., 2012. The invasive venomous striped eel catfish *Plotosus lineatus* in the Levant: Possible mechanisms facilitating its rapid invasional success. *Marine Biology*, 159, 283-290.
El-Zarka, S. El-Din, Koura, R., 1965. Seasonal fluctuations in production of the principal edible fish in the Mediterranean Sea off the United Arab Republic. Proceedings of G.F.C.M. 8, 227-259.
Essl, F., Bacher, S., Blackburn, T. M., Booy, O., Brundu, G. *et al*., 2015. Crossing frontiers in tackling pathways of biological invasions. *BioScience*, 65 (8), 769-782.
EU, 2014. European Union Regulation No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Brussels, http://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX-%3A32014R1143.
Evans, T., Kumschick, S., Blackburn, T. M., 2016. Application of the Environmental Impact Classification for Alien Taxa (EICAT) to a global assessment of alien bird impacts. *Diversity and Distributions*, 22 (9), 919-931.
Fish, R., Church, A., Willis, C., Winter, M., Tratalos, J. A. *et al*., 2016a. Making space for cultural ecosystem services: insights from a study of the UK Nature Improvement Initiative. *Ecosystem Services*, 21, 329-343.
Fish, R., Church, A. Winter, M., 2016b. Conceptualising cultural ecosystem services: a novel framework for research and critical engagement. *Ecosystem Services*, 21, 208-217.
Freshwater, D. W., Hamner, R. M., Parham, S., Wilbur, A. E., 2009. Molecular evidence that the lionfishes *Pterois miles and Pterois volitans* are distinct species. *Journal of the North Carolina Academy of Science*, 125 (2), 39-46.
Fricke, R., Golani, D., & Appelbaum-Golani, B., 2017. *Arnoglossus nigrofilamentosus* n. sp., a new species of flounder (Teleostei: Bothidae) from off the Mediterranean coast of Israel, probably a new case of Lessepsian migration. *Scientia Marina*, 81 (4), 457-465.
Giakoumi, S., 2014. Distribution patterns of the invasive herbivore *Siganus luridus* (Ruppell, 1829) and its relation to native benthic communities in the central Aegean Sea, Northeastern Mediterranean. *Marine Ecology*, 35 (1), 96-105.
Golani, D., 1993. The biology of the Red Sea migrant, *Saurida undosquamis* in the Mediterranean and comparison with the indigenous confamilial *Synodus saurus* (Teleostei: Synodontidae). *Hydrobiologia*, 271 (2), 109-117.
Golani, D., 2000. First record of the bluespotted cornetfish from the Mediterranean Sea. *Journal of Fish Biology*, 56 (6), 1545-1547.
Golani, D., 2002. The Indo-Pacific striped eel catfish, *Plotosus lineatus* (Thunberg, 1787), (Osteichthyes: Siluriformes) a new record from the Mediterranean. *Scientia Marina*, 66 (3), 321-323.
Golani, D., Edelist, D., Lerner, A., Sonin, O., Motro, U., 2017. A long term (1949-2010) study of catch and effort in Israeli trawl fishery, Eastern Mediterranean Sea. *Acta Adriatica*, 58, 157-162.
Goodenough, A., 2010. Are the ecological impacts of alien species misrepresented? A review of the "native good, alien bad" philosophy. *Community Ecology*, 11 (1), 13-21.
Green, S. J., Akins, J. L., Maljković, A., Côté, I. M., 2012. Invasive lionfish drive Atlantic coral reef fish declines. *PloS one*, 7 (3), e32596.
Green, S. J., Dulvy, N. K., Brooks, A. M., Akins, J. L., Cooper, A. B. *et al*., 2014. Linking removal targets to the ecological effects of invaders: a predictive model and field test. *Ecological Applications*, 24 (6), 1311-132c2.
Gücü, A. C., Bingel, F., 1994. Trawlable species assemblages on the continental shelf of the northeastern Levant Sea (Mediterranean) with an emphasis on Lessepsian migration. *Acta Adriatica*, 35 (1), 83-100.
Gücü, A. C., Bingel, F., 2011. Hake, *Merluccius merluccius* L. in the northeastern Mediterranean Sea: a case of disappearance. *Journal of Applied Ichthyology*, 27 (4), 1001-1012.
Gweta, S., Spanier, E., Bentur, Y., 2008. Venomous fish injuries along the Israeli Mediterranean coast: Scope and characterization. *The Israel Medical Association Journal*, 10 (11), 783-788.
Hawkins, C. L., Bacher, S., Essl, F., Hulme, P. E., Jeschke, J. M. *et al*., 2015. Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity and Distributions*, 21 (11), 1360-1363.
Henderson, E. B., 2012. *Economic and ecological implications of interactions between lobsters and invasive lionfish in the Bahamas.* MSc thesis, Biological Sciences Department,

University of British Columbia, Canada, 95pp.
Ingeman, K. E., 2016. Lionfish cause increased mortality rates and drive local extirpation of native prey. *Marine Ecology Progress Series,* 558, 235-245.
Jimenez, C., Andreou, V., Hadjioannou, L., Petrou, A., Alhaija, R. A. *et al*., 2017. Not everyone's cup of tea: Public perception of culling invasive lionfish in Cyprus. *Journal of the Black Sea /Mediterranean Environment*, 23 (1), 38-47
Jimenez, C., Petrou, A., Andreou, V., Hadjioannou, L., Wolf, W. *et al*., 2016. Veni, vidi, vici: The successful establishment of the lionfish *Pterois miles* in Cyprus (Levantine Sea). *Rapport Commission International Mer Mediterranee*, 41, 417.
Joksimović, A., Dragičević, B., Dulčić, J., 2009. Additional record of Fistularia commersonii from the Adriatic Sea (Montenegrin coast). *Marine Biodiversity Records*, *2*.
Kalogirou, S., Corsini, M., Kondilatos, G., Wennhage, H., 2007. Diet of the invasive piscivorous fish *Fistularia commersonii* in a recently colonized area of the eastern Mediterranean. *Biological Invasions,* 9 (8), 887-896.
Kalogirou, S., 2013. Ecological characteristics of the invasive pufferfish *Lagocephalus sceleratus* (Gmelin, 1789) in Rhodes, Eastern Mediterranean Sea. A case study. *Mediterranean Marine Science*, 14 (2), 251-260.
Karachle, P. K., Stergiou, K. I., 2017. An update on the feeding habits of fish in the Mediterranean Sea (2002-2015). *Mediterranean Marine Science*, 18 (1), 43-52.
Karachle, P.K., Corsini-Foka, M., Crocetta, F., Dulcic, J., Djhembekova, N. *et al*., 2017. Setting up a billboard of marine invasive species in the ESENIAS area: current situation and future expectancies. *Acta Adriatica* 58 (3), 429-458.
Katsanevakis, S., Tempera, F., Teixeira, H., 2016. Mapping the impact of alien species on marine ecosystems: the Mediterranean Sea case study. *Diversity and Distributions*, 22 (6), 694-707.
Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M. E. *et al*., 2014. Impacts of Invasive Alien Marine Species on Ecosystem Services and Biodiversity: a pan-European Review. *Aquatic Invasions,* 9 (4), 391-423.
Katsanevakis, S., Zenetos, A., Belchior, C., Cardoso, A. C., 2013. Invading European Seas: assessing pathways of introduction of marine aliens. *Ocean & Coastal Management*, 76, 64-74.
Kelly, J., Tosh, D., Dale, K., Jackson, A., 2013. *The economic cost of invasive and non-native species in Ireland and Northern Ireland*. A report prepared for the Northern Ireland Environment Agency and National Parks and Wildlife Service as part of Invasive Species Ireland, 86.
Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U. *et al*., 2009. *Assessment of the impacts of IAS in Europe and the EU*. Technical support to EU strategy on invasive alien species (IAS). London: Institut for European Environmental Policy (IEEP).
Kindinger, T. L., Albins, M. A., 2017. Consumptive and non-consumptive effects of an invasive marine predator on native coral-reef herbivores. *Biological Invasions*, 19(1), 131-146.
Kletou, D., Hall-Spencer, J.M., Kleitou, P., 2016. A lionfish (*Pterois miles*) invasion has begun in the Mediterranean Sea. *Marine Biodiversity Records* 9, 46.
Kraus, F., 2015. Impacts from invasive reptiles and amphibians. *Annual Review of Ecology, Evolution, and Systematics*, *46*, 75-97.
Kumschick, S., Bacher, S., Dawson, W., Heikkilä, J., Sendek, A. *et al*., 2012 A conceptual framework for prioritization of invasive alien species for management according to their impact. *NeoBiota,* 15, 69-100.
Kumschick, S., Bacher, S., Evans, T., Markova, Z., Pergl, J. *et al.,* 2015. Comparing impacts of alien plants and animals in Europe using a standard scoring system. *Journal of Applied Ecology*, 52 (3), 552-561.
Kumschick, S., Measey, G. J., Vimercati, G., Villiers, F. A., Mokhatla, M. M. *et al*., 2017. How repeatable is the Environmental Impact Classification of Alien Taxa (EICAT)? Comparing independent global impact assessments of amphibians. *Ecology and evolution*, 7 (8), 2661-2670.
La Rosa, D., Spyra, M., Inostroza, L., 2016. Indicators of cultural ecosystem services for urban planning: a review. *Ecological Indicators*, 61, 74-89.
Latombe, G., Pyšek, P., Jeschke, J. M., Blackburn, T. M., Bacher S. *et al.*, 2017. A vision for global monitoring of biological invasions. *Biological Conservation*, 213 (B), 295-308.
Lazarre, D., 2016. *Examining the lionfish invasion: How growth and recruitment relates to connectivity and controls*. PhD Thesis, University of Miami, Florida, 153pp.
Lesser, M. P., Slattery, M., 2011. Phase shift to algal dominated communities at mesophotic depths associated with lionfish (Pterois volitans) invasion on a Bahamian coral reef. *Biological Invasions*, 13 (8), 1855-1868.
Loomis, J. B., White, D. S., 1996. Economic benefits of rare and endangered species: summary and meta-analysis. *Ecological Economics*, 18, 197-206.
Malpica Cruz, L., Haider, W., Smith, N. S., Fernández-Lozada, S., Côté, I. M., 2017. Heterogeneous attitudes of tourists towards lionfish in the Mexican Caribbean: Implications for invasive species management. *Frontiers in Marine Science*, 4, 138, doi: 10.3389/fmars.2017.00138
McBride, M. F., Garnett, S. T., Szabo, J. K., Burbidge, A. H., Butchart, S. H. *et al*., 2012. Structured elicitation of expert judgments for threatened species assessment: a case study on a continental scale using email. *Methods in Ecology and Evolution*, 3 (5), 906-920.
McGeoch, M. A., Butchart, S. H., Spear, D., Marais, E., Kleynhans, E. J. *et al.* 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Diversity and Distributions*, 16 (1), 95-108.
McGeoch, M. A., Genovesi, P., Bellingham, P. J., Costello, M. J., McGrannachan, C. *et al.,* 2016. Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. *Biological Invasions*, 18 (2), 299-314.
MEA, 2003. Millenium Ecosystem Assessment. Ecosystems and human well-being: a framework for assessment. Washington, DC: Island Press.
Mumby, P. J., Hastings, A., Edwards, H. J., 2007. Thresholds and the resilience of Caribbean coral reefs. *Nature,* 450, 98-101.
Nader, M., Indary, S., Boustany, L., 2012. *The Puffer Fish Lagocephalus Sceleratus (Gmelin, 1789) in the Eastern Mediterranean.* EastMed Technical Documents (FAO*)*. GCP/INT/041/EC-GRE- ITA.
Narayan, D., Chambers, R., Shah, M. K., Petesch, P., 2000. *Voices of the Poor: Crying out for Change*. New York: Oxford University Press for the World Bank.
Nentwig, W., Kühnel, E., Bacher, S., 2010. A Generic Impact-Scoring System Applied to Alien Mammals in Europe. *Conservation Biology*, 24 (1), 302-311.
Nuñez, M. A., Kuebbing, S., Dimarco, R. D., Simberloff, D., 2012. Invasive species: to eat or not to eat, that is the question. *Conservation Letters*, 5 (5), 334-341.
Ondrias JC, 1971. A list of the fresh and seawater fishes of Greece. *Hellenic oceanology and limnology*, 10, 23-96.
Otero, M., Cebrian, E., Francour, P., Galil, B. Savini, D., 2013. *Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): A strategy and practical*

guide for managers. Malaga, Spain: IUCN, 136.
Ounifi-Ben Amor, K., Rifi, M., Ghanem, R., Draief, I., Zaouali, J. *et al.,* 2016. Update of alien fauna and new records from Tunisian marine waters. *Mediterranean Marine Science*, 17 (1), 124-143.
Panagopoulou, A., Meletis, Z. A., Margaritoulis, D., Spotila, J. R., 2017. Caught in the Same Net? Small-Scale Fishermen's Perceptions of Fisheries Interactions with Sea Turtles and Other Protected Species. *Frontiers in Marine Science*, 4, 180. doi:10.3389/fmars.2017.00180.
Pancucci-Papadopoulou, M.A., Kalogirou, S., 2013. Invasion of silverstripe blaasop in Rhodes Island, Greece. In: Invasive alien species: the urban dimension Case studies on strengthening local action in Europe. Compiled by Van Ham, C., Genovesi, P., and Scalera, R. Brussels, Belgium: IUCN European Union Representative Office. 103pp.
Pennington, A., Shepperson, J., Jeffery, A., Miliou, A., Anagnostou, V., 2013. *Siganus* species in an artisanal fishery in the Eastern Aegean. *Rapport Commission International Mer Mediterranee*, 40, 591.
Pinnegar, J. K., Tomczak, M. T., Link, J. S., 2014. How to determine the likely indirect food-web consequences of a newly introduced non-native species: A worked example. *Ecological Modelling*, 272, 379-387.
Polishchuk, Y., Rauschmayer, F., 2012. Beyond "benefits"? Looking at ecosystem services through the capability approach. *Ecological Economics*, 81, 103-111.
Rabitsch, W., Genovesi, P., Scalera, R., Biała, K., Josefsson, M. *et al*., 2016. Developing and testing alien species indicators for Europe. *Journal for Nature Conservation*, 29, 89-96.
Resiere, D., Cerland, L., De Haro, L., Valentino, R., Criquet-Hayot, A. *et al*., 2016. Envenomation by the invasive Pterois volitans species (lionfish) in the French West Indies - a two-year prospective study in Martinique. *Clinical Toxicology*, 54 (4), 313-318.
Robeyns, I., 2005. The capability approach: a theoretical survey. *Journal of human development*, 6 (1), 93-117.
Robeyns, I., 2011. The capability approach. *The Stanford Encyclopedia of Philosophy* (ed. E.N. Zalta), http://plato.stanford.edu/archives/sum2011/entries/capability-approach.
Roy, H. E., Adriaens, T., Aldridge, D. C., Bacher, S., Bishop, J. D. D. *et al.,* 2015. *Invasive Alien Species - Prioritising prevention efforts through horizon scanning*. ENV.B.2/ETU/2014/0016. European Commission.
Roy, H. E., Rabitsch, W., Scalera, R., Stewart, A., Gallardo, B. *et al*., 2017a. Developing a framework of minimum standards for the risk assessment of alien species. *Journal of Applied Ecology*, 10.1111/1365-2664.13025.
Roy, H., Rabitsch, W., Scalera, R., 2017b. *Study on Invasive Alien Species - Development of risk assessments to tackle priority species and enhance prevention*. Final Report for the European Commission. pp 839.
Russell, R., Guerry, A. D., Balvanera, P., Gould, R. K., Basurto, X. *et al.*, 2013. Humans and Nature: How Knowing and Experiencing Nature Affect Well-Being. *Annual Review of Environment and Resources*, 38, 473-502.
Sala, E., Kizilkaya, Z., Yildirim, D., Ballesteros, E., 2011. Alien marine fishes deplete algal biomass in the Eastern Mediterranean. *PLoS One* 6, 1-5.
Salomidi, M., Giakoumi, S., Gerakaris, V., Issaris, Y., Sini, M. *et al.,* 2016. Setting an ecological baseline prior to the bottom-up establishment of a marine protected area in Santorini Island, Aegean Sea. *Mediterranean Marine Science*, 17 (3), 720-737.
Sanchez-Tocino, L., Hidalgo Puertas, F., Pontes, M., 2007. Primera cita de *Fistularia commersonii* Ruppell, 1838 (Osteichtyes: Fistulariidae) en aguas mediterráneas de la Península Ibérica. *Zoologica Baetica*, 18, 79-84.
Scalera, R., 2010. How much is Europe spending on invasive alien species? *Biologal Invasions,* 12, 173-177.
Sen, A., 1999. *Commodities and Capabilities*. Oxford University Press, New Delhi. https://ideas.repec.org/b/oxp/obooks/9780195650389.html
Shakman, E., Kinzelbach, R., 2007. Commercial fishery and fish species composition in coastal waters of Libya. *Rostocker Meeresbiologische Beiträge*, 18, 63-78.
Simberloff, D., Martin, J. L., Genovesi, P., Maris, V., Wardle, D. A. *et al*., 2013. Impacts of biological invasions: What's what and the way forward. *Trends in Ecology and Evolution,* 28, 58-66.
Situ, Y. Y., Sadovy, Y. J., 2004. A preliminary study on local species diversity and seasonal composition in a Hong Kong wet market. *Asian Fisheries Science*, 17 (3), 235-248.
Streftaris, N., Zenetos, A., 2006. Alien marine species in the Mediterranean-the 100 'Worst Invasives' and their impact. *Mediterranean Marine Science*, 7 (1), 87-118.
Tollington, S., Turbe, A., Rabitsch, W., Groombridge, J. J., Scalera, R. *et al*., 2017. Making the EU legislation on invasive species a conservation success. *Conservation Letters*, 10 (1), 112-120.
Tsagarakis, K., Coll, M., Giannoulaki, M., Somarakis, S., Papaconstantinou, C. *et al*., 2010. Food-web traits of the North Aegean Sea ecosystem (Eastern Mediterranean) and comparison with other Mediterranean ecosystems. *Estuarine, Coastal and Shelf Science*, 88 (2), 233-248.
Tsagarakis, K., Palialexis, A., Vassilopoulou, V., 2014. Mediterranean fishery discards: review of the existing knowledge. *ICES Journal of Marine Science*, 71 (5), 1219-1234.
Turbé, A., Strubbe, D., Mori, E., Carrete, M., Chiron, F. *et al*., 2017. Assessing the assessments: evaluation of four impact assessment protocols for invasive alien species. *Diversity and Distributions,* 23 (3), 297-307.
UNEP, 2014. Convention on Biological Diversity (CBD). http://www.cbd.int/ (accessed 18 January 2018)
Ünal, V., Göncüoğlu Bodur, H. G., 2017. The socio-economic impacts of the silver-cheeked toadfish on small-scale fishers: a comparative study from the Turkish coast. *Journal of Fisheries and Aquatic Sciences (Su Ürünleri Dergisi)*, 34 (2), 119-127.
Ünal, V., Göncüoğlu, H., Durgun, D., Tosunoğlu, Z., Deval, M. C. *et al*., 2015. Silver-cheeked toadfish, *Lagocephalus sceleratus* (Actinopterygii, Tetraodontiformes: Tetraodontidae), causes a substantial economic losses in the Turkish Mediterranean coast: A call for decision makers. *Acta Ichthyologica et Piscatoria*, 45, 231-237.
van Beukering, P., Brouwer, R., Schep, S., Wolfs, E., Brander, L. *et al.*, 2014. *The impact of invasive species on tourism. The case of lionfish in the Cayman Islands*. IVM Institute for Environmental Studies Report R-14/32, 50pp
Vanderhoeven, S., Branquart, E., Casaer, J., D'Hont, B., Hulme, P. E. *et al*., 2017. Beyond protocols: improving the reliability of expert-based risk analysis underpinning invasive species policies. *Biological Invasions,* 19, 2507-2517.
van Ham, C., Genovesi, P., Scalera, R., 2013. *Invasive alien species: the urban dimension, case studies on strengthening local action in Europe*. IUCN, Brussels, Belgium.
Vergés, A., Tomas, F., Cebrian, E., Ballesteros, E., Kizilkaya, Z. *et al*., 2014. Tropical rabbitfish and the deforestation of a warming temperate sea. *Journal of Ecology*, 102 (6), 1518-1527.
Vijayakumaran, K., 1998. Growth and mortality parameters and some aspects of biology of striped eel catfish *Plotosus lineatus*

(Thunberg) from north Andhra Pradesh coast. *Journal of the Marine Biological Association of India*, 39 (1 & 2), 108-112.

Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P. *et al*., 2010. How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in Ecology and the Environment*, 8(3), 135-144.

Visser, V., Wilson, J. R., Canavan, K., Canavan, S., Fish, L. *et al*., 2017. Grasses as invasive plants in South Africa revisited: Patterns, pathways and management. *Bothalia-African Biodiversity & Conservation*, 47 (2), 1-29.

Williams, F., Eschen, R., Harris, A., Djeddour, D., Pratt, C. *et al*., 2010. *The economic cost of invasive non-native species on Great Britain*. CABI Proj No VM10066, 1-99.

Williams, S. L., Davidson, I. C., Pasari, J. R., Ashton, G. V., Carlton, J. T. *et al*., 2013. Managing Multiple Vectors for Marine Invasions in an Increasingly Connected World. *Bioscience,* 63, 15.

Yemisken, E., Dalyan, C., Eryilmaz, L., 2014. Catch and discardfish species of trawl fisheries in the Iskenderun Bay (Northeastern Mediterranean) with emphasis on lessepsian and chondricthyan species. *Mediterranean Marine Science*, 15 (2), 380-389.

Zenetos, A., Gofas, S., Morri, C., Rosso, A., Violanti, *et al*., 2012. Alien species in the Mediterranean Sea by 2012. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part 2. Introduction trends and pathways. *Mediterranean Marine Science,* 13, 328-352.

Zenni, R. D., Nuñez, M. A., 2013. The elephant in the room: The role of failed invasions in understanding invasion biology. *Oikos,* 122, 801-815.