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REVIEW ARTICLE

Europen Union (EU) Risk Assessment of *Plotosus lineatus* (Thunberg, 1787); a summary and information update

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Abstract

Plotosus lineatus is a venomous Lessepsian fish species present in the south-eastern Mediterranean since 2002. It has been identified as one of the priority marine invasive alien species (IAS) likely to threaten native ecosystems and human well-being throughout the Mediterranean and within EU marine waters. It was thus selected as one of the species to be risk assessed and considered for management under the EU IAS Regulation. This work describes the main findings of the Risk Assessment (RA) of *P. lineatus* and discusses possible management measures. The species has a high likelihood to enter the RA area through natural dispersal and the possibility of "facilitated" or accidental escapes from domestic or public/private aquaria, has been established in some parts of the Mediterranean and is very likely to establish throughout the Mediterranean and possibly the Black Sea. Potential population explosions can instigate major environmental impacts on native community structure and ecosystem functions through competition, predation and habitat use; additionally, its painful and potentially dangerous sting poses a serious health risk. The risk assessment identified a moderate rate of spread due to depth limitations to dispersal, which can facilitate population control and containment efforts, should they be needed. Commercialization of the species for consumption and biomedical research can be an option for long-term management.

Keywords: *Plotosus lineatus*, striped eel catfish, invasive, risk assessment, management measures, EU IAS Regulation

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Introduction

Recognizing that invasive alien species (IAS) pose one of the biggest threats to biodiversity and associated ecosystem services, the European Union (EU) in its Biodiversity Strategy, Target 5, committed to taking specific actions to combat IAS (EC 2011). One of these actions was the adoption of legislation, i.e. EU Regulation (No.1143/2014), which establishes rules to prevent, minimize and mitigate the adverse impact on biodiversity of IAS (EU 2014). The Regulation introduces a priority list of IAS of Union concern, selected on the basis of specified inclusion criteria (outlined in Article 4), compliance with which is ascertained by detailed Risk Assessment (RA), according to provisions made in Article 5. Thus, an RA is an absolute requirement for any species to be considered for management at the EU or the regional level. A detailed RA being labor intensive as well as a decisive step in the implementation of the IAS Regulation, it has to be preceded by a rigorous prioritization process to determine which species constitute the best candidates to be risk assessed and subsequently be proposed for inclusion in the "Union list". One of the species identified by the latest EU horizon scanning exercise (Roy *et al*. 2015; 2018) as a priority species was the lessepsian fish *Plotosus lineatus* (Thunberg, 1787), with the tenth highest score among species of all taxonomic groups. The species was also identified by a Joint GFCM-UN Environment/MAP working group as one of the seven priority fish alien species for monitoring in the Eastern Mediterranean in relation to fisheries (GFCM-UNEP/MAP 2017).

The striped eel catfish *P. lineatus*, native to the Indo-Pacific, was first reported in the Mediterranean Sea by Golani (2002) and, by 2016, had established itself along the Levantine coast as far as Iskenderun Bay in Turkey (Doğdu *et al*. 2016). Despite its rather slow rate of spread, it has the potential for impressive population explosions and has been suspected of displacing native fishes through competition (Edelist *et al*. 2012). It is also a venomous fish with a painful and potentially dangerous sting (Haddad 2016) and is a well-known aquarium species (Chan and Sadovy 2000; DEH-Australian Government 2005). Additionally, it has been used as a model organism to study osmoregulation (e.g. Kolbadinezhad *et al*. 2018) and the potential use of its venom in biomedical applications (Shiomi *et al*. 1988; Fahim *et al*. 1996). Considering that Target 5 of the EU Biodiversity strategy states that "By 2020, Invasive Alien Species and their pathways are identified and prioritised, priority species are controlled or eradicated, and pathways are managed to prevent the introduction and establishment of new IAS", the European Commission instigated a series of projects to help achieve these objectives timely, one of which is titled "Study on Invasive Alien Species – Development of risk assessments to tackle priority species and enhance prevention" (EC 2018). *Plotosus lineatus* was selected as one of the first 10 species to be risk assessed within the framework of the first year of this project. The risk assessment was undertaken in 2017 and was revised in 2018, following comments by the

Member States' appointed representatives in the Scientific Forum. In this paper, we aim to present the main findings of this RA and discuss potential management measures, as stipulated by the IAS Regulation.

Materials and Methods

In this study we employed a Risk Assessment protocol developed in the framework of the EU commissioned program ENV.B2.ETU/2016/0013, which explicitly addresses all the requirements set out in the EU Regulation (No.1143/2014) (EC 2018) and meets the 13 minimum standards for risk assessment identified by Roy *et al.* (2017). The protocol was based on the RA Scheme developed by the GB Non-Native Species Secretariat (GB Non-Native Risk Assessment - GBNNRA) and comprises different sections, presenting basic organism information, describing the distribution of the organism, current and potential (under current and future climate conditions) and addressing with a series of questions the four main aspects of the invasion process; Introduction, Establishment, Spread and Impacts. The RA area covers all European Seas excluding the outermost regions, i.e. Guadeloupe, French Guiana, Martinique, Saint Martin, Réunion, Mayotte (France); the Canary Islands (Spain); and the Azores and Madeira (Portugal). The description of pathways of introduction and spread follows the recent guidelines for the interpretation of the Convention for Biological Diversity (CBD) classification (CBD 2014, IUCN 2017). The main factors considered for the assessment of the likelihood of introduction include the commodities it may be associated with, the reproductive strategy of the species (i.e. number of propagules that can travel along each pathway in one year), its ability to survive passage along each pathway and transfer to suitable habitats in the recipient areas and the effectiveness of existing management practices to detect it or affect its survival. A similar suite of factors was addressed in the risk of spread section, which also takes into account the documented spread of the species in the invaded area. Regarding the potential for establishment, particular emphasis is given to the physiological requirements of the species and its reproductive strategy in relation to the conditions encountered in the RA area. In addition to the relevant literature, the Ocean Biogeographic Information System (OBIS) and Global Biodiversity Information Facility (GBIF) databases were consulted for distribution records of the species, which were then matched with global annual mean sea surface temperature (SST) maps. At the regional EU scale, suitable abiotic parameters (monthly SST datasets) were also retrieved from the platform Copernicus Marine Services (URL:http://marine.copernicus.eu/services-portfolio/access-to-products/,product GLOBAL_REP_PHY_001_021).

Future climate conditions for mapping and distribution assessment purposes were considered as an overall 2 °C SST increase by 2098, projected according to the RCP4.5 scenario of the Intergovernmental Panel on Climate Change (IPCC) which corresponds to medium-high anthropogenic radiative forcing (RF); an increase in SST of up to 3.7 °C is predicted under the RCP8.5 scenario corresponding to high anthropogenic RF (IPCC 2013). Possible biotic interactions in the form of predation, competition and parasitism are also considered. In the magnitude of impacts section, different sets of questions address environmental impacts; impacts on ecosystem services, economic impacts, and social and human health impacts. Authors are asked to assess separately the demonstrated impacts inside and outside the RA area and further provide an expert opinion on the potential future impacts. This distinction has to be presented as clearly as possible in order to aid Member States to arrive at their decision regarding the possibility of listing with all its implications. The scoring guidelines of the Impacts Section are largely based on the Environmental Impact Classification of Alien Taxa / EICAT (Blackburn *et al.* 2014) and Socio-Economic Impact Classification of Alien Taxa / SEICAT (Bacher *et al*. 2018) impacts assessment schemes for environmental and socio-economic impacts respectively and are governed by the same principles. Each answer provided in the risk assessment is assigned a confidence score based on the availability of sufficient and conclusive information to answer the question. Finally, as a supplement to the RA, a Management Annex describes and evaluates a suite of possible management measures, ranging from pre-invasion stage (i.e. prevention) measures to population control and mitigation of impacts with an evaluation of their feasibility and cost-effectiveness. Peer reviewed scientific publications were the main source of information on the biology, ecology, distribution, spread and demonstrated impacts of the species; these were supplemented with extensive personal communications with national experts in the (potentially) affected regions to elucidate establishment status and the potential for management and with representatives of organizations /associations related to the commodities that may mediate introductions or further spread (i.e. the European Union Aquarium Curators – EUAC, the European Association of Zoos and Aquaria - EAZA and the Ornamental Aquatic Trade Association representing retailers in the UK and Europe – OATA). Three years after the last published expansion record in the Mediterranean, we also include in this manuscript some recent information on the presence of *P. lineatus* along the Turkish Levantine coast.

Results and Discussion

This risk assessment resulted in an overview and an update of the available information relevant to evaluating the invasiveness potential of *P. lineatus*. Thus, through extensive personal communications with scientists and stakeholders, we offer new information on the establishment of the species in Turkey. We also present data on the presence of the species in the aquarium trade and in large public aquaria, provided by OATA and EUAC/EAZA respectively, which was crucial for the assessment of the pathways of introduction with reasonable confidence. Furthermore, by clarifying details on the species' life-cycle and eco-physiological requirements, we provide an estimate of *P. lineatus's* potential for establishment and spread in European Seas.

Organism information & Distribution

Plotosus lineatus is considered an amphidromous marine catfish species that is known to enter estuaries and withstand brackish water conditions (Froese and Pauly 2019). The four pairs of barbels together with the shape and characteristic stripped coloration distinguish it from any other Mediterranean fish species (Otero *et al*. 2013). Native to the Indo-Pacific, from Japan to Australia, East Africa and the Red Sea, the species lives in a variety of coastal benthic habitats as well as the open coast (Froese and Pauly 2019). The distribution of *P. lineatus* in the invaded range until 2017 is depicted in Figure 1. The first Mediterranean record was reported from Israel (Golani 2002), where *P. lineatus* underwent a population explosion within the next few years (Edelist *et al*. 2012). Northward expansion followed, with records in Lebanon (Bitar 2013), Syria (Ali *et al*. 2015) and Turkey (Doğdu *et al*. 2016). After the first occurrence of *P. lineatus* in Iskenderun Bay, Turkish Levantine coast in 2016, its population is increasing, while different sizes of the species are also being observed, indicating its establishment in the region (C. Turan, personal observation). The species is also present and considered established in Egypt (Temraz and Ben Souissi 2013) and Tunisia (Ounifi Ben Amor *et al*. 2016).

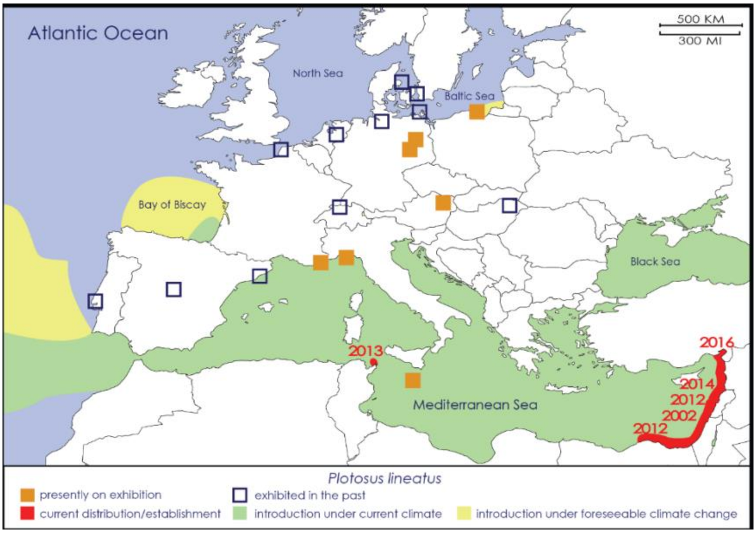

Figure 1. Current and potential distribution map of *Plotosus lineatus*, with locations where public aquaria are currently displaying or have in the past displayed the species. Green represents areas where current mean SST in July is ≥ 21°C (averaged over 2012-2016), yellow represents additional areas where the same conditions will be met under a 2°C SST increase scenario by 2098 (IPCC 2013). For further details see Methods & Risk of Establishment section.

P. *lineatus* has demersal eggs and demersal larvae (Moriuchi and Dotsu 1973; Leis 1991). It reaches sexual maturity after 1-3 years (Thresher 1984), its fecundity ranges from 525 to 1176 eggs per year (Heo *et al*. 2007) and spawning in both the native and the invaded range occurs in the summer (see Edelist *et al*. 2012 and references therein). Eggs are deposited in shallow inshore areas under rocks and other large pieces of debris on sandy bottoms and the nest is guarded by the male (Clark *et al*. 2011). The demersal larvae have a life-span of 10-15 days (Moriuchi and Dotsu 1973) and are likely to be carried by bottom currents for some distance but still remain nearshore (Leis 1993) until they reach the juvenile free-swimming stage, after which they start swarming, i.e. form large "balls" consisting of hundreds of juveniles (Figure 2). Juveniles forage in the daytime over sandy and muddy areas, algal beds, on and in coral reef structures and retire at night under reef/rock ledges or artificial structures; *P. lineatus* adults are solitary or occur in small groups of up to 20. Adults are nocturnal and known to hide under ledges or caves during the day (Clark *et al*. 2011) such that they are not readily observed by scuba divers during daytime (C. Turan, personal observation). The species is carnivorous, feeding mainly on molluscs, worms, fish and crustaceans (Fischer *et al*. 1990), with the latter two groups being dominant in the diet of the invasive populations (Golani 2002; Edelist *et al*. 2012).

Figure 2. Schooling of *P. lineatus* in Iskenderun Bay, Turkish Levantine coast. (Photograph by Cemal Turan)

Risk of Introduction & Associated Pathways

The RA identified four potential pathways of introduction into EU marine waters. Corridor (in EU waters Introduction via the Suez Canal) is considered the primary pathway of introduction into the Mediterranean Sea - recipient countries are located in the Levantine basin and continuous introductions are considered very likely (Table 1). This is followed by natural dispersal (Unaided pathway), as indicated by the expansion of *P. lineatus* in a gradual progression from the Suez Canal towards the north-east Mediterranean. This pattern of spread, often against the prevailing currents along the Suez Canal, suggests that spread by adult migration and movement of juveniles play a strong role in the dispersal of the species. This is corroborated by the lack of pelagic larvae and the ecology of the juveniles. The pathways "Corridor" and "Unaided" were scored as very likely with high confidence as the introduction to RA neighbouring areas has already happened (Table 1). An additional pathway we considered was "Escape from Confinement" both as a "Pet/aquarium/terrarium species" (intentional release into the wild) and from "Botanical gardens/zoo/ aquaria" and "Research/*ex situ* breeding" facilities (unintentional). Even though *P. lineatus* is a popular ornamental species in the US (Rhyne *et al*. 2012), in the UK and Europe, the retail trade in this species is low (Murray and Watson 2014). The Ornamental Aquatic Trade Association representing retailers in the UK (OATA) estimates that in relation to the UK, sales of this species would be in the region of 300 individuals per year. 20 to 50% of sales are not to retail but to public aquaria and research institutions (OATA, pers.comm., May 2018). These figures may also represent re-export to other countries (Leal *et al*. 2016). Thus, *P. lineatus* can be purchased and kept in private aquaria in all EU countries. Unwanted pet animals released in marine waters can easily survive and find a suitable habitat in parts of the EU where the abiotic conditions are favourable (i.e., the Mediterranean Sea, the Black Sea and a limited area of the Iberian coast and the Bay of Biscay – see section on Establishment for details).

Table 1. Risk of introduction

Pathway of Introduction	Response	Confidence level
CORRIDOR (Suez Canal)	Very likely	High
UNAIDED	Very likely	High
ESCAPE FROM CONFINEMENT (Pet/aquarium/terrarium species)	Moderately likely	Medium
ESCAPE FROM CONFINEMENT (Zoos/aquaria & Research/ex situ breeding)	Moderately likely	Medium

Additionally, the species can escape from aquaria or research facilities based near the sea as a result of a failure in (or inadequate) management practices. Accidental escape of larvae or a small swarm of juveniles is assumed to be the life stage that is most likely to enter the RA area through this pathway. According to information provided by EUAC (40% response rate) and EAZA, *P. lineatus* in 2017-2018 was on display in 8 large aquaria within the RA area and has been displayed in another 11 aquaria in the past (Figure 1). It is apparent from Figure 1 that there are currently at least three aquaria where release may occur to potentially suitable habitat; Genova, Monaco, Malta. It is assumed that large public aquaria and research facilities follow strict biosecurity measures in accordance with legislation. Accidental escape of eggs or larvae through failure in management measures is considered more likely in smaller public or private aquaria, for which the little available information (OATA, see above) does not have a spatial component. Moreover, the species can reproduce in captivity and survive outside its exhibition tank (*P. lineatus* larvae originating from the exhibition tank had grown into juveniles in a sand filter in Tivoli aquarium, Denmark – Lars Skou Olsen, pers. comm.). A failure in management measures may result in the accidental entry of the organism into European Seas. Considering the rather small numbers of *P. lineatus* in the aquarium trade and the information gaps, both "Escape from confinement" pathways were scored as moderately likely with medium confidence (Table 1).

Risk of Establishment - Eco-physiological requirements & their availability

Based on OBIS records (OBIS 2017), *P. lineatus* in the native range is found at sea surface temperatures between 21-29°C annual mean. Spawning occurs between May-July in various parts of the native range with a peak in June in Korea (Heo *et al*. 2007), and between temperatures of 21-27°C in Japan (Moriuchi and Dotsu 1973). Reported recruitment of juveniles in Israel between July-September (Edelist *et al*. 2012), combined with the life-cycle characteristics described in previous sections indicate that spawning in the Mediterranean also occurs in early to mid-summer. We thus considered as a "limiting factor" for establishment a temperature of at least 21°C in July. Suitable temperature conditions are currently met in the Mediterranean, Black Sea and the Iberian coast and the Bay of Biscay marine regions. With particular reference to the Iberian coast and the Bay of Biscay, sea surface temperatures (SST) of 21°C in July are currently observed in the south coast of Portugal and in the Bay of Biscay (2012-2016 SST average, calculated from monthly means). Regarding salinity requirements, *P. lineatus* is an euryhaline species with a wide salinity tolerance range (Froese & Pauly 2019). *P. lineatus* held in experimental conditions can tolerate salinities between 2-52 ppt (Job 1959), while in the wild there is evidence that the species is commonly found in river estuaries in Singapore, with recorded salinities as low as 12 ppt (Goh and Goh 1989; Sin *et al*. 1991). It is thus considered very likely to be able to penetrate the Sea of Marmara, where both its salinity and temperature requirements are met. Based on the above information, establishment in the rest of the Black Sea (salinities of 14-18 ppt) may also be possible but this prediction has a low confidence due to uncertainty associated with the species' ability to complete its full life cycle under permanently reduced salinity conditions.

It should also be noted that in the Bay of Biscay establishment may occur only after a new introduction event via a human-mediated pathway as unaided dispersal is assumed to be limited to southern Portugal. This event is not considered very likely (see Risk of Introduction section). In a future scenario of temperature increase by 2°C, temperature requirements will be met further north along the west coast of Portugal and for more prolonged periods in the summer over the whole potential range (Figure 1). The Bay of Biscay will provide more suitable habitat for establishment but the likelihood of introduction in this region remains low. The likelihood of establishment is not anticipated to be greatly affected by biotic interactions; *P. lineatus* has overlapping feeding and habitat use habits with a number of native Mediterranean fishes in the Levant (Arndt *et al*. 2018) – see Impacts section for details – and has successfully established in the region despite this overlap, it is thus assumed to be a successful competitor. Moreover, predators of *P. lineatus* in the Mediterranean are considered scarce (Edelist *et al*. 2012). Besides, nest guarding, the swarming behavior of the juveniles and the venomous spines and toxic skin of the species offer additional protection from predation (Clark *et al*. 2011).

Table 2. Risk of establishment

MSFD Marine region/subregion	**Response**	**Confidence level**
Mediterranean Sea	Very likely	High
Bay of Biscay and the Iberian Coast, Black Sea (only as far as the Sea of Marmara)	Moderately likely	Low
Baltic Sea, Greater North Sea, Celtic Seas	Unlikely	High

Risk of Spread

The primary mechanism of spread for *P. lineatus* once it enters the RA area will be natural dispersal (unaided pathway), similar to the introduction pathway. The life history of the species however is important in order to evaluate the rate of spread. *P. lineatus* is known from depths of down to 83 m and is characterized by demersal development and a benthivorous diet. The short life cycle and demersal nature of the larvae and the population explosion of *P. lineatus* in Israel point to larval retention (see also Levin 2006). It appears that post-larval dispersal of the juveniles and adults has driven the spread of this species in the Mediterranean so far; however, it is probably left to the adults to cross large distances isolated by deeper waters. The juveniles move incessantly over sand while feeding so it is unlikely that they will venture or survive well into deep waters where food is more scarce. The adults are considered much more likely to move to deeper waters, especially if the local population has reached high densities. Its invasion history to date indicates a moderate rate of spread of approximately 100km per year and this is anticipated to continue over suitable habitats along continuous coastlines. Considerable uncertainty on the rate of spread towards islands separated by deep waters is associated with the perceived depth limitation described above. As a case in point, six years after the first record in Tunisia in 2013 (Ounifi Ben Amor *et al*. 2016) and 5 years after the reports of schools of juveniles in Syria (Ali *et al*. 2015), there are no published records of *P. lineatus* in either Sicily or Cyprus waters, where recording efforts of invasive fishes are generally high.

Apart from natural dispersal, two additional pathways were considered in the assessment of the risk of spread (Table 3). One is related to the aquarium trade (Escape from Confinement), whereby specimens could be collected from the wild and sold for private and public aquaria or further re-exported from aquarium shops. Capturing individuals from the wild to supply the aquarium trade is common practice for reef fishes in general and *P. lineatus* in particular (Chan and Sadovy 2000; DEH-Australian Government, 2005) and there is anecdotal information that this is already happening for other ornamental invasive fishes in the Mediterranean, such as *Pterois miles* (Bennett, 1828) and *Sargocentron rubrum* (Forsskål, 1775). Because no import declarations or licenses are required for intra-EU movement of goods, *P. lineatus* could spread in EU aquarium/pet shops undetected unless a dedicated search was conducted, it is considered however unlikely that it can transfer to a suitable habitat during the transport process, hence an unlikely score for this pathway. The other possible pathway we examined was Release in nature through fisheries discards, which could potentially facilitate the species to overcome depth limitations at a local scale. This will depend on the densities the species has achieved at depths where trawling is permitted (deeper than 50 m in EU waters), the time of the year, the trawling effort, the discard practices and, most importantly, the mortality rate of *P. lineatus* discards for which little is known. Due to the considerable uncertainty pertaining to all the aforementioned factors, this pathway was scored as unlikely with low confidence.

Table 3: Risk of spread

Pathway of spread	**Response**	**Confidence level**
UNAIDED	Very likely	Very high
ESCAPE FROM CONFINEMENT (captured and sold to the aquarium trade)	Unlikely	Medium
RELEASE IN NATURE (other intentional release – fisheries discards)	Unlikely	Low
RATE OF SPREAD (continuous coastline)	Moderately rapidly	High

Magnitude of Impacts

Thus far, impacts of *P. lineatus* have ben manifested only outside the RA area, primarily the Israeli coast, where the species attained high densities in shallow waters <37m (Edelist *et al.* 2012). An earlier hypothesis that *P. lineatus* might be responsible for the competitive displacement of the native fish species *Trachinus draco* (Edelist *et al*. 2012) was not supported by further analyses, which rather implicated the stripped eel catfish in the competitive exclusion of *Mullus barbatus* and *Mullus surmuletus* which have declined by approximately one order of magnitude in the shallow sandy coasts of Israel over the past 20 years (Arndt *et al*. 2018). This was based on an analysis of the overlap in depth-range distribution, diet and habitat use between *P. lineatus* and a suite of lessepsian fish species (Arndt *et al.* 2018). The ecological role of *P. lineatus* in invaded habitats has not been adequately studied, however potential impacts include competition with native species for food and habitat, predation pressure on crustacea and other preferred prey, deleterious effects on naïve predators and the potential to drastically change the structure of native communities in the invaded areas (Otero *et al.* 2013). Feeding swarms of juveniles with their constant probing of the sand may increase turbidity and alter properties of the sediment (Cline *et al.* 1994) with consequences for sediment resuspension and nutrient cycling (Yahel *et al.* 2002). Current environmental impacts were thus scored as moderate but future potential impacts can be major under a worst-case scenario (Table 4); both assessments received a low confidence score.

Its socio-economic impacts are much better documented (Galanidi *et al.* 2018); the species constituted a large component (up to 17.7% of individuals in shallow waters) of the by-catch in trawl fisheries in Israel, increasing the time needed to sort the catch, causing injuries with its venomous spines and forcing shrimp fishermen to change the time and place of fishing (Edelist *et al.* 2012). The depth limit of 50m for trawling (and locally deeper) and the seasonal (spring/summer) fisheries closures in the Mediterranean EU states are likely to limit the high discard rates of *P. lineatus* in trawl catches compared to what was observed in Israel, where such restrictions were not in place at the time of Edelist *et al.* (2012). In countries however with a large trawling fleet (e.g. Italy, Greece, Croatia – FAO 2016), the net impact may be comparable, depending on the densities achieved.

Regarding health impacts, numerous (n>100) injuries to fishermen and beachgoers have been recorded by the Poison Information Center in Rambam Health Care Campus, Haifa, Israel (Gweta *et al.* 2008; Edelist *et al.* 2012, Bentur *et al*. 2018), some of them involving severe pain, hypertension and tachycardia as well as secondary infections. Mild symptoms were mostly self-treated, especially by fishermen. Injuries to fishermen have started to occur in Turkey as well, where *P. lineatus* is appearing in fisheries catches. The first clinical case was documented by Turan *et al.* (2019); it was a sting to the forefinger of a fisherman on a commercial trawler in Iskenderun Bay. The fisherman experienced severe pain and was immediately taken to the emergency department, where the wound was treated with the application of heat. Discarded fish, washed ashore and stepped on or picked up by people walking on the beach were the main cause of injury to beach-goers in Israel (Daniel Golani, pers.comm.). In such injuries, a common complication is the breakage of stingers in the wound. If the fish have rotted, this is associated with a higher likelihood of severe bacterial infection (Haddad 2016). Currently, health impacts are scored as moderate, applying the precautionary principle however, we concluded that potential future health impacts in the RA area can be major with a low confidence.

Table 4. Assessment of Impacts Sc=Score, Cl=Confidence level

ENVIRONMENTAL	Current	Future
Biodiversity		
Predation (crustacea, fish, molluscs, worms)	Sc: Moderate	Sc: Major
Competition for food & shelter	Cl: Low	Cl: Low
Ecosystem functioning		
Ecosystem services	Sc: Moderate	Sc: Minor
Food provisioning (interferes with fisheries)	Cl: Medium	Cl: Medium
Conservation value		
Soft-sediment & hard habitats	Sc: Moderate	Sc: Moderate
Seagrass & algal beds	Cl: Low	Cl: Low
SOCIO-ECONOMIC		
Economic impacts		
High discard rates (increase sorting time)	Sc: Moderate	Sc: Minor
Fishermen change place and time of fishing	Cl: Medium	Cl: Medium
Social & human health impacts		
Injuries to fishermen and beach-goers	Sc: Moderate	Sc: Major
Secondary infections	Cl: Medium	Cl: Low

Prevention-Management

Member States need to evaluate invasiveness potential, and particularly the magnitude of impacts, against what is achievable and cost-effective in terms of management (Booy *et al*. 2017) and indeed define management objectives depending on the time elapsed since introduction (Adriaens *et al*. 2018). In terms of prevention, there are no measures that can prevent a naturally dispersing organism already present in the Mediterranean from reaching the RA area. It is however entirely possible to minimize or even eliminate additional entry points via aquaria-related pathways by better informing the public on the risks of releasing *P. lineatus* into the environment, by improving biosecurity measures in aquaria and implementing stricter controls and finally by regulating and possible banning the trade of *P. lineatus* (i.e. including it in EU 1143/2014). A ban on sale would be unlikely to have a major impact on the aquarium industry, it may however have some negative implications for public aquaria and research institutions. Since the organism is not yet present in the EU, an effective regulating mechanism could be the adaptation of the EU Trade control and Expert System (TRACES), which is currently used to track imports of species from third countries, to gather compulsory information on the intra-EU trade of *P. lineatus* and other ornamental species (Biondo 2017).

Early warning systems for the detection of the organism in the wild are in place in a number of Mediterranean EU countries through the networks of local experts with stakeholders, national and regional collaboration platforms on invasive/alien species (e.g. ESENIAS, Karachle *et al.* 2017), citizen science programmes and the press. Such initiatives have proven to be effective for the early detection of Lessepsian invasive fishes (Andaloro *et al.* 2016: Azzurro *et al.* 2017), at least in the juvenile and adult stages of the organisms. Existing reporting tools and coordinating national experts are explicitly mentioned in the *P. lineatus* risk assessment. Further monitoring can be achieved through scientific (e.g. MEDITS International bottom trawl survey in the Mediterranean Sea) and fisheries dependent surveys and should focus on the areas of the first expected entry points via natural dispersal. These are: Sicily from Tunisia, Cyprus from Syria and/or Turkey and the Dodecanese islands from Turkey once *P. lineatus* reaches the Aegean coast of Turkey. Towards the same end, in a recent pilot study it was proposed that *P. lineatus* is monitored through the Data Collection Reference Framework (DCRF) of EU Member States and the discards monitoring program of the General Fisheries Commission for the Mediterranean (GFCM – UNEP/MAP 2018). These are all cost-efficient measures which are utilizing existing monitoring mechanisms and can also be combined with national Marine Strategy Framework Directive (MSFD) monitoring plans.

Once the organism has been detected consideration must be given to the subsequent course of action. Eradication in the marine environment is generally considered very difficult (Sambrook *et al.* 2014) and has only been achieved in a handful of cases, when the introduced species had limited dispersal capabilities, the populations were small and restricted, human and financial resources were available, and early action was taken (Williams and Grosholz 2008). In the case of *P. lineatus*, eradication is considered unrealistic and efforts will be negated by continuous propagule pressure from neighbouring populations and/or the Suez Canal. On the other hand, population control and even containment in some localities, i.e. prevention of further spread, may be feasible considering the depth limitations to spread. Containment/population control would most likely require a long-term commitment over consecutive years over localized areas (Barbour *et al*. 2011), involving intensive targeted fishery and would entail a considerable cost.

Removal efforts with bottom towed gear (such as e.g. trawling) would be impractical (legal impediments) and unadvised as they would be destructive for native species and habitats, particularly sensitive and protected habitats such as reefs and seagrass beds. *P. lineatus* can be captured with different fishing methods as well, i.e. seine nets, cages, spearfishing (Ali *et al.* 2015; 2017), angling (Gil Rilov, pers.comm), but the efficiency of these gears for large-scale removal is not known. Concerted efforts with multiple gears and possibly a payment reward scheme can form the first course of action.

Their degree of success notwithstanding, subsidized removals are not a sustainable long-term solution. If the species becomes widely established, a commercial, regulated fishery may be a better option for long-term population control and damage restriction, provided that protecting native ecosystems takes precedence over maximizing market profits. In addition to being a model organism for animal physiology and biomedical research, *P. lineatus* in its native range is considered edible and is exploited by small scale fishermen (Vijayakumaran 1997; Manikandarajan *et al*. 2014); similar uses could be promoted in the invaded range too. In this context, including *P. lineatus* in the list of species covered by the landings obligation of the EU Common Fisheries Policy (a.k.a. the Discard Ban) would encourage commercial exploitation, alleviate some of the economic and health impacts of the species (i.e. injuries to beach-goers), and help control any potential human-assisted spread through fisheries discards. Finally, awareness campaigns to fishermen and the general public for the dangerous sting of the species and how to safely handle the organism and treat the injuries are an essential part of the management plan. Due to the nocturnal nature of adult *P. lineatus,* a special warning to night divers is warranted.

Even if *P. lineatus* is not selected as a species of Union concern, it most certainly can be considered a species of regional concern which requires enhanced regional cooperation not only among EU Member States but, more importantly at this stage, between all Mediterranean countries. Monitoring and reporting through the aforementioned FAO/GFCM pilot study is a promising step, as is the planned re-activation of the MAMIAS (Marine Mediterranean Invasive Alien Species) platform as a repository for marine IAS data (UNEP/MAP 2017a). Harmonisation of methodologies and policy targets is also enhanced by strategies adopted within the Barcelona convention, such as the "Strategic Action Plan for the conservation of marine and coastal biodiversity in the Mediterranean" (SAP-BIO) and the "Action Plan concerning Species Introductions and Invasive Species in the Mediterranean Sea" (UNEP/MAP 2017a,b).

Summary

Plotosus lineatus, as a Lessepsian immigrant, has established populations in countries of the Levant and Tunisia and will very likely enter the RA area through natural dispersal. Parallel introduction events via aquarium trade (accidental or intentional release) and/or as escapee from public/private aquaria and research facilities are also a possibility (albeit not very likely) that may not have as notable an effect as natural dispersal but nevertheless increase the number of potential entry points for the species. Considering that the biological characteristics of the species are such that natural dispersal towards and within the EU will likely proceed at a moderately rapid rate, hampered by deep waters that separate islands from coastal regions, such anthropogenically induced events gain a bigger importance. The EU marine subregions that face a higher risk of invasion are the Mediterranean Sea, to a lesser degree the Black Sea as far as the Sea of Marmara and small parts of the Bay of Biscay and the Iberian coast. Future climate conditions are anticipated to extend the area suitable for establishment considerably only in the Bay of Biscay, where an introduction event was deemed not very likely to begin with; however, higher temperatures during a prolonged period in the summer may boost spawning and trigger population explosions, which *P. lineatus* is known for (Edelist *et al.* 2012).

Current impacts in the Levantine coast were evaluated as moderate at all levels, however this assessment is not directly transferable to the RA. At high densities, *P. lineatus* has the potential to alter native community structure and ecosystem functions through competition, predation and habitat use; its future environmental impacts were thus assessed as potentially major. On the other hand, spatial and temporal fishing restrictions in the EU are likely to limit by-catch/discard rates in fisheries and result in lower socio-economic impacts in the RA area. These same restrictions however are assumed to afford protection to both the spawning and the early life stages of the species and thus enhance its establishment potential. Given the high risk of establishment and the widespread injuries in the invaded area, the potential future health impacts in the RA area were assessed as major, especially since they can involve systemic manifestations and serious secondary infections (Bentur *et al.* 2018). It was thus concluded that *P. lineatus* is a high risk species for the EU and should be considered for inclusion in the Union list.

Addendum

While this manuscript was in press, the EU Member States, represented by the Scientific Forum, accepted the inclusion of *Plotosus lineatus* in the list of species of Union concern, under its second update.

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