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Management in Practice

Twenty five years of invasion: management of the round goby *Neogobius melanostomus* in the Baltic Sea

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Abstract

The round goby, *Neogobius melanostomus* (Pallas, 1814), is one of the most invasive non-indigenous species in the Baltic Sea. It dominates coastal fisheries in some localities and is frequently found in offshore pelagic catches. This paper identifies management issues and suggests actions to be considered for post-invasion management. Priority should be given to the establishment of a coordinated pan-Baltic monitoring programme and associated data storage and exchange, as well as the compilation of landing statistics of the round goby in commercial and recreational fisheries. While eradication is unrealistic, population control that leads to minimising the risk of transfer to yet uncolonised areas in the Baltic Sea and adjacent waterbodies is feasible. This should comprise the requirement that the species be landed in commercial fishery bycatch, the management of ships' ballast water and sediments, and hull fouling of inland and sea-going vessels, including recreational boats. Extensive involvement of stakeholders is crucial at all phases of the management process.

Key words: non-native, marine environment, legislative framework, fisheries, ecological and human dimension

Introduction

Non-indigenous species (NIS) can substantially change local biodiversity, modify the structure and functions of aquatic ecosystems, alter ecosystem services and even threaten human health (Bax et al. 2003; Katsanevakis et al. 2014). Therefore, NIS are considered as important as other anthropogenic drivers that affect marine ecosystems, such as exploitation of living marine resources, habitat destruction and pollution (European Community 2008; 2010). However, only a subset of NIS is widespread (Galil et al. 2014) and known to pose major ecological and economic harm. These NIS should be a priority for post-invasion management actions.

In the Baltic Sea over 100 NIS have been recorded (AquaNIS 2014), but only one fifth are widespread (Ojaveer and Kotta 2015). One of the widespread and most successful NIS in the region is the round goby, *Neogobius melanostomus* (Pallas, 1814). Of Ponto-Caspian origin, it has established large populations in the Baltic Sea, several major Eurasian rivers and the North American Great Lakes (Kornis et al. 2012). In the Baltic Sea, the round goby was first observed in the Gulf of Gdansk, Poland in 1990, and has since spread to all the Baltic countries (AquaNIS 2014). Studies in the Baltic Sea have identified a dietary overlap between the round goby and the flounder, *Platichthys flesus* (Linnaeus, 1758), and documented a negative correlation between their abundances (Karlson et al. 2007; Järv et al. 2011). The round goby also predates on eggs of commercially valuable fish (Fitzsimons et al. 2006 and references therein), reduces the density of benthic invertebrates, which are shared prey with numerous native species (Lederer et al. 2008), bioaccumulates contaminants such as mercury or polychlorinated biphenyls (PCBs) from polluted sediments (Ng et al. 2008; Azim et al. 2011), and functions as a vector of botulism to avian predators (Yule et al. 2006).

Given the widespread ecological consequences, legislation and international policies play an important role in controlling this species. Therefore it ought to be considered an "invasive species of regional concern" – see Article 11 of Regulation (EU) 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 (IAS Regulation) (European Community 2014a). In addition, the invasion of the round goby into the Baltic Sea should also be handled in the context of the following international legislative acts: the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWMC) (IMO 2004); the EU Marine Strategy Framework Directive (MSFD) (European Community 2008); the Commission Decision on criteria and methodological standards on good environmental status of marine waters (European Community 2010), and the EU Biodiversity Strategy to 2020 (European Community 2011). Regarding human health, nature conservation and fisheries management, the Commission Decision setting maximum levels for certain contaminants in foodstuffs (European Community 2001), the Directive on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) (European Community 1992) and the Common Fisheries Policy (CFP) (European Community 2013) should be considered.

Although the eradication of NIS in aquatic ecosystems has generally proved unsuccessful (Williams and Grosholz 2008), a coordinated post-invasion management policy may reduce population abundance, mitigate ecological impact and curtail secondary spread. The purpose of this contribution is to review characteristics of the round goby invasion, which in turn will help to identify priority actions for coordinating post-invasion management of the species in the Baltic Sea.

Post-invasion management issues

1. Pan-Baltic data collection and dissemination

Internationally coordinated monitoring programmes are in place in the Baltic Sea with respect to several native species/populations/communities of primary producers and invertebrates, as well as offshore and coastal fish(eries) (HELCOM 1988; 2006; ICES 2014). These programmes provide some information on NIS, but due to the fragmentary nature and lack of dedicated NIS monitoring in most Baltic countries, systematic and timely data on NIS is scarce (ICES 2012). Further, none of the programmes has been designed to provide reliable information on the spread and abundance of mobile epifauna (incl. demersal fish). Planning and implementing a monitoring programme that meets MSFD requirements, including NIS (European Community 2008; 2010), is however underway in the EU member states.

Due to round goby's relatively sedentary lifestyle and male nestguarding behaviour, there is a need to design and adapt conventional survey methodology for monitoring (Brandner et al. 2013). This includes identification of appropriate sampling sites in invaded areas and probable target sites. With appropriate survey methodology and sampling gear, information could also be gathered on other non-indigenous mobile epifaunal species, such as the mud crab *Rhithropanopeus harrisii* (Gould, 1841) which has recently colonised new areas and is increasing in abundance (Fowler et al. 2013), and the Chinese mitten crab *Eriocheir sinensis* H. Milne Edwards, 1853 which has pan-Baltic distribution (Ojaveer et al. 2007) and may be targeted by the EU IAS regulation, and thus requires monitoring. Alongside routine monitoring activities, a programme of 'citizen science' may serve as an effective tool for early detection (Delaney et al. 2008; Bodilis et al. 2014). In the Baltic Sea, national reporting systems for recording citizens' observations are in place in Finland, Sweden, and Denmark (FGFRI 2011; Artportalen 2013; Kristensen et al. 2014), and should be extended elsewhere. If widely used, these national reporting systems are especially useful in incorporating data from recreational catches. Mandatory catch records of the round goby should also be required by all Baltic Sea countries: data on commercial catches of the round goby are only available for Estonia and Latvia, whereas in Finland, Poland and Sweden the data is recorded amongst 'gobiids' or 'other fish'. Denmark lacks bycatch data despite a substantial bycatch in some coastal fisheries.

2. Ship-mediated dispersal

Prevention is the principal management action to reduce the introduction and spread of new NIS in the marine realm (Lehtiniemi et al. 2015). As the round goby has already established almost pan-Baltic populations, actions should focus on minimising the risk of spread to yet uncolonised areas through management of the suggested invasion vectors (LaRue et al. 2011; AquaNIS 2014).

Although the tolerance of the species' eggs and larvae to oceanic salinities remains to be investigated, based on the evidence available (Ellis and MacIsaac 2009 and references therein; Karsiotis et al. 2012) management of the round goby should focus on actions to minimise the risk of introduction to the adjacent waterbodies (essentially the North Sea, as well as Baltic rivers and lakes). Hull fouling of vessels may accommodate mobile fauna and serve as substrate for eggs, possibly in the least exposed locations, such as sea-chests (Coutts and Dodgshun 2007; Frey et al. 2014) and small holes, such as ballast water intake holes (Wonham et al. 2000). The latter have been argued to contribute to the successful introduction and establishment of gobiids by facilitating the dispersal phase of their invasion process (Wonham et al. 2000).

Transport in ballast tanks is considered the most likely vector of the round goby invasion into the Laurentian Great Lakes and the Baltic Sea, as the populations in both regions are genetically similar to the population near the southern Dnieper River at Kerson, Ukraine, a major Black Sea port (Brown and Stepien 2008; 2009). The same vector is the likely cause for its secondary spread in the Laurentian Great Lakes, by nocturnal intake of ballast water containing larvae and juveniles (Hensler and Jude 2007; Hayden and Miner 2009). Ballast treatment and management, as mandated by the BWMC (IMO 2004), is essential for limiting the spread of the round goby within the region and to the connected waterbodies.

3. Population control

Direct removal of NIS as a means of eradicating a local population may serve as a management option under certain circumstances; for example, a newly established, localized population of an organism that has limited dispersal capabilities (Willan et al. 2000; Culver and Kuris 2004; Wotton et al. 2004; Anderson 2005). This clearly excludes the round goby as it is already widely dispersed. However, removal may be locally effective for population control: culling in Pefferlaw Brook, Ontario, Canada, has initially proven efficient in slowing down dispersal of the species (Dimond et al. 2010), but long-term effects are yet to be confirmed. In suitable areas with high-density populations, angling may be encouraged as a management option for controlling population size and mitigating impacts locally.

The round goby has a relatively small home range (Ray and Corkum 2001), but may occasionally move long distances (Kornis et al. 2012). Experiments have shown strong negative intraspecific interactions among individuals, resulting in reduced food intake and dramatically lower growth rates at densities of about 10 fish per m^2 (Kornis et al. 2014). Negative density-dependent effects on individual growth have also very recently been demonstrated in the field, where population densities of 1.9 fish per m^2 showed significantly poorer growth and condition compared to conspecifics from the adjacent, recently invaded area with densities of 0.01 fish per m^2 (Azour et al. 2015). Both these studies have suggested further dispersal due to these negative density-dependent effects. Indeed, molecular tools demonstrate that 1.9% of individuals in lakes and 7.3% of individuals in rivers are likely first-generation, long-distance immigrants (Bronnenhuber et al. 2011).

Classical biocontrol – "use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be" (Eilenberg et al. 2001) – involves the deliberate introduction of NIS and has proven efficacious in controlling native and introduced terrestrial pests (Caltagirone 1981; McFadyen 1998; Clewley et al. 2012). Attempts of biocontrol in marine ecosystems are very few, and only a handful of them have been successful (Lafferty and Kuris 1996; Goddard et al. 2005; Carman et al. 2009). A successful biocontrol case in freshwater habitats includes the stocking of Pacific salmonids which effectively reduced alewife populations in the Laurentian Great Lakes (Fenichel et al. 2010). Genetic biocontrol (i.e., the deliberate environmental release of genetically manipulated organisms that are designed to disrupt the survival or reproduction of a targeted invasive species) is an attractive tool as it is species-specific, reversible under a range of different scenarios and potentially efficient to the point of possible eradication (Kapuscinski and Sharpe 2014; Thresher et al. 2104). Predators of the round goby in the Baltic Sea include cod, *Gadus morhua* (average 22.4% of diet by mass; Almqvist et al. 2010); perch

Perca fluviatilis (average 69.2% of diet by mass; Almqvist et al. 2010; average 17.4% of predator's nutrition; Rakauskas et al. 2013), northern pike *Esox lucius* (frequency in diet up to 25.4% Reyjol et al. 2010), pikeperch *Sander lucioperca* (17.5% of predator's nutrition; Rakauskas et al. 2013) and turbot *Psetta maxima* (no quantitative data; Sapota and Skora 2005). In several coastal regions, the abundance of these piscivorous fish is low due to intense exploitation (HELCOM 2006; Vetemaa et al. 2010), so effective control of the goby population through predation is unlikely.

In addition to predatory fish, the great cormorant *Phalacrocorax carbo* (60–90% of diet by number; Bzoma 1998; 11.9% of predator's nutrition; Rakauskas et al. 2013) and the grey heron *Ardea cinerea* (95% of diet by number; Jakubas 2004; 6.9% of predator's nutrition; Rakauskas et al. 2013) may also be important predators of the round goby and their role in assisting in potential regulation of the round goby population should be taken into account.

4. Management of nature conservation areas

The effect of NIS on native communities and habitats has been receiving increasing attention (e.g., European Community 2004). However, management plans for marine protected areas (MPAs) rarely include guidelines for NIS management (Burfeind et al. 2013).

MPAs cover approximately 12% of the total area of the Baltic Sea (HELCOM 2013a) and consist mainly of the Natura 2000 network of marine protected areas based on the Habitats Directive (European Community 1992) and the Birds Directive (European Community 2009), as well as the Baltic Sea Protected Areas of the Baltic Marine Environment Protection Commission – Helsinki Commission (HELCOM), the latter mainly as an outcome of the HELCOM Baltic Sea Action Plan (HELCOM 2007). The main objective of MPAs is to protect valuable and threatened species, communities and habitats. Protected areas at national level have various management objectives, for example, recovery of commercially exploited fish stocks (Fenberg et al. 2012). Notably, most MPAs are situated in shallow coastal waters, comprising habitats suitable for the round goby.

Article 2(1) of the Habitats Directive defines the overall aim as "... *to contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora*" with Article 2(2) specifying measures taken "... *shall be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest.*" Furthermore, Article 6 (1) states: *"For special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans, and appropriate statutory, administrative or contractual measures which correspond to the ecological requirements of the natural habitat types ... and the species ... present on the sites*" (European Community 1992). As the round goby may exert a significant impact on benthic communities (Kuhns and Berg 1999; French and Jude 2001; Barton et al. 2005; Kipp et al. 2012), its presence may compromise conservation goals, since MPAs may serve as dispersal hubs for the round goby and induce 'spill-over effect' to adjacent areas (but see Bronnenhuber et al. 2011). This may compromise achieving Good Environmental Status (GES) of several descriptors of the MSFD: Descriptor 1 "*Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions*", Descriptor 4 "*All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity*" and Descriptor 6 "*Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected*" (European Community 2010). Active removal of invasive NIS from MPAs, including the round goby, should be allowed, even encouraged and facilitated.

5. Contaminants uptake

Through the creation of new trophic links in the invaded systems (e.g., Johnson et al. 2005; Almqvist et al. 2010), the invasion of the round goby has not only resulted in the increase in bioaccumulation of sediment-related toxins in predatory fishes, but also caused biomagnification of several toxic substances in the marine food chain (e.g. Kwon et al. 2006; Hogan et al. 2007; Marentette et al. 2010; Azim et al. 2011; but see Kornis et al. 2012). As both the round goby and its predators (piscivorous fish, see Crane et al.

2015) are consumed by humans, human health may be at risk. Since aquatic pollution may increase the relative success of invasive species (Crooks et al. 2011) and the round goby is known to be tolerant to contamination (McCallum et al. 2014), the risk is even greater.

Furthermore, the potential increase of residuals of contaminants further up the food-web may compromise achieving GES of the MSFD Descriptor 8 ("*Concentrations of contaminants are at levels not giving rise to pollution effects*") and Descriptor 9 ("*Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards*") (European Community 2010).

6. Stakeholder involvement

Stakeholders, including residents in areas likely to be affected by the invasion of NIS and the proposed control options for mitigation of impacts, must be informed and consulted throughout the management process. Ideally, this should include setting objectives, reviewing alternatives and weighing the benefits of control options against their risks and the risk(s) of no action (Bax et al. 2001). Dialogue with stakeholders is likely to raise awareness of the socio-ecological problems that may be caused by the given bioinvasion. Understanding the attitudes and concerns of residents towards potential management measures can also help researchers, conservationists and legislators to understand the challenges and opportunities that may be encountered during the development and application of such measures (Trenouth and Campbell 2013; Sharpe 2014).

Recommendations for post-invasion management actions

1. Pan-Baltic data collection and dissemination

As indicated above, currently no round goby monitoring occurs and we depend on sporadic and irregular data sources, which are inadequate for accurate estimation of their abundance and biomass. Collection, validation and timely dissemination of accurate information on the abundance and distribution are therefore prerequisite for undertaking successful management actions (Lehtiniemi et al. 2015). A Pan-Baltic programme comprising harmonized protocols for targeted monitoring, fisheries data and citizen science observations would provide information on the dispersal as well as population status of the fish. The information collected should also serve for any rapid response actions and be linked to the process of proposing potential changes in national fisheries regulations to secure effective biocontrol (i.e., certain abundance level of large predatory fish in the sea). Importantly, adjacent waterbodies should be monitored for secondary spread, which may enable rapid eradication actions.

Thus, we should attempt to first arrive at validated estimates of the current status of the round goby populations based on an appropriate monitoring programme. The second step is to initiate discussions on management options and launch pilot control experiments of the species at the pan-Baltic scale.

Considering the need for standardization and amalgamation of NIS observations (Ojaveer et al. 2014), a pan-Baltic clearinghouse should be established, and the regional management body, e.g., HELCOM (or its affiliate), be established as a central contact point.

2. Pan-Baltic management of vessel-transported propagules

Ratification and early adoption of the BWMC by the Baltic countries would help to reduce ballast-transported propagules of the round goby. Monitoring for NIS in major ports in the Baltic Sea is a crucial component for management decisions, which will enable an estimate of the likelihood of ship-transported spread (IMO 2004; HELCOM 2013b). Furthermore, round goby should be considered a 'red flag' species when granting exemptions from the BWMC (IMO 2004).

Given its notorious euryhalinity, restriction of secondary spread into Baltic rivers and lakes and the North Sea would necessitate the strict application of the International Maritime Organisation's guidelines to minimise the risk of transfer of invasive aquatic species via hull fouling (IMO 2011). This would also raise further awareness among marine operators and recreational boaters of the necessity and importance of antifouling maintenance.

3. Population control

3.1. Fishery

The exploitation of living marine resources in the Baltic Sea is regulated at various levels, depending on the resource in question. One of the objectives of the Basic Regulation of the CFP (Regulation 1380/2013 European Community) is to "*... gradually eliminate discards...*" (as a conservation measure for commercially exploited fish stocks and/or marine ecosystems), taking into account the best scientific advice. The landing obligation includes the requirement to develop discard plans which contain detailed operational guidelines on the handling and storage of the fish both onboard and on land. An open and transparent discussion needs to occur around the possibility to include provisions for dealing with bycatch of the round goby. Such measures could be considered as precautionary (reducing risk of deliberate release to yet uncolonised water bodies/sea areas, potentially reducing ecological impact) and accompanied by monitoring/research efforts. These ideas should be discussed and developed in cooperation with the appropriate stakeholder groups, with the purpose of encouraging the use of this new marine living resource.

The potential of the recreational fishery to control population abundance should also be explored. If experimental findings support its efficacy, regional management plans and policy documents should be revised to allow and even promote a recreational fishery for round gobies. These may include examples such as angling (Gutowsky et al. 2011) especially in areas and at times where recreational fishering might otherwise be restricted (e.g., MPA's). However, we anticipate that bycatch will continue to be an issue given the lack of selectivity and limited number of goby-specific techniques that can be employed in a recreational angling setting. It is therefore very likely that gear development (modifying the already existing and/or development of new selective gear specific for the round goby) is needed.

3.2. Manipulation of predation pressure

Classical biocontrol is considered highly risky due to possible adverse effects on non-target species (Simberloff and Stiling 1996; Ip et al. 2014). Therefore it cannot be recommended as a management tool for marine NIS (Bax et al. 2001; Atalah et al. 2015). Moreover, the EU has been especially averse to authorizing the use of genetically modified organisms, even as crops (European Commission 2014b). To justify the expense of research and testing needed to obtain legal approval, an evaluation of the impacts of the round goby and a thorough assessment of the risks and benefits involved have to be unequivocably demonstrated.

Native piscivorous predators in the Laurentian Great Lakes may be able to control the population of the round goby (Madenjian et al. 2011; Burkett and Jude 2015). However, quantitative studies on native Baltic fish predating on the round goby are few and no species has been convincingly pinpointed for control purposes, although tentative suggestions have been made (Rakauskas et al. 2013). Fundamental research efforts are required prior to suggesting the use of piscivorous fish (or birds) as biocontrol agents and, in turn, proposing potential changes in national fisheries regulations to secure a certain abundance level of large predatory fish. These should cover, among others, both ecological (e.g., identification of prey preference of piscivorous fish and quantitative predator-prey relationships in coastal fish communities invaded by the round goby) and socio-economic issues (e.g., stakeholder attitudes, economic implications, market responses).

Simultaneous application of the landing obligation of the round goby (a requirement that the species be landed and recorded in commercial fisheries) and securing effective control by native predators (both piscivorous fish and birds) may result in reduced populations of the round goby and thereby mitigate socio-economic impacts (e.g., income reduction for fishers due to decline of target species in some coastal fisheries as a consequence of the goby's domination).

Combining culling through removal by fishers with enhanced predation pressure may reduce its abundance and thereby reduce the risk of further spread. However, it is likely that some long-and short-distance dispersal will occur and may undermine control efforts (Bronnenhuber et al. 2011).

Pre-border prevention is indeed the preferred option for NIS management. However, when the introduction has already occurred, and the impacts warrant intervention, population control (e.g., through predation by native piscivores or active removal) may reduce or delay secondary spread to adjacent water bodies. Early detection and rapid response in the Baltic Sea (*sensu lato*) may be useful for yet largely uninvaded subsystems (i.e., Bothnian Sea and Bothnian Bay in the northern Baltic Sea). Furthermore, there is a growing body of evidence that predation by native fish can control/reduce goby abundance (see above). Therefore, management agencies could perform risk analyses (ecological and socio-economic) and results may guide responses to suit local conditions.

4. Protocols for rapid response to newly detected populations

At present, no model exists for mobilizing a rapid response to newly detected populations of the round goby. A pan-Baltic rapid response plan should be structured in order to avoid political/ bureaucratic/funding obstacles that might impede actions. The plans should be ready for activation in a time frame that can maximize the possibility for control (including eradication). At the same time, such a rapid response plan would also help in the management of other invasive NIS in the area.

5. Controlling the round goby in nature conservation areas

The first priority action is to closely monitor the status of the round goby populations inside nature conservation areas. If the species is detected, the management regime already in place should be reassessed and removal of the round goby considered/planned (see section 3.1. above). Allowing active removal operations of invasive NIS in conservation areas, such as MPAs, may require changes in legislation.

Efficient protection of conservation areas can be achieved only when surrounding areas adhere to management plans, when close cooperation and information exchange among all relevant authorities (nature conservationists and fishery managers) are in place, and when coherent management measures within and adjacent to nature conservation areas are jointly agreed upon.

6. Monitoring of contaminants

Levels of contaminants (European Community 2001) in round goby populations possibly intended for human consumption should be closely monitored, as the fish inhabits some of the most polluted coastal areas (Sapota et al. 2005). This monitoring should be conducted as part of the population abundance monitoring in order to be cost efficient.

Only if levels are within safe limits could the round goby be utilized for human consumption by commercial and recreational fishers. Otherwise, alternate treatment options of the landed catch should be sought.

7. Securing stakeholder involvement

Considering the lack of appropriate surveys and monitoring programmes for the round goby (see above), one of the key roles of stakeholders in the Baltic Sea (essentially recreational and commercial fishers) is to act as a primary source for observational and catch data (e.g., FGFRI 2011), and eventually to help control the goby populations through the exploition of this new resource. A low reporting threshold can be obtained by establishing easy-to-use websites (see FGFRI 2011).

Several international bodies in the Baltic Sea region should be involved in communicating, awareness raising, and discussing and developing potential management options, i.e., the Baltic Sea Advisory Council, HELCOM and the Baltic Sea Fisheries Forum, BALTFISH. In addition, the recreational sector at large should also be engaged, by including recreational fishing associations, recreational boat owners and port/marina managers (ICES 2013).

Of particular importance is regular and management step-specific outreach (Dimond et al. 2010) to representatives from policy advisors, fishermen, license issuers, nature conservationists, marine spatial planners and maritime lawyers. It should also include demonstration and public participation at practical events such as goby angling/fishing competitions (e.g., SKES 2015). Public outreach should comprise the full societal range from schools to community and tourist centres. Such a wide civil involvement would enhance overall awareness of NIS invasions.

Concluding remarks

The management of NIS requires a transborder, transdisciplinary and integrated approach, with stakeholders taking part at all stages and in all components of the process. Efficient marine management can only be achieved when managers within the sector are willing to think across the vertical and horizontal levels of integration (Elliott 2014). In addition, adoption of the 'single authority' approach by establishing a single national/regional coordinating body for NIS management is highly recommended (Ojaveer et al. 2014). This will help to incorporate bioinvasions, one of the most important human-induced pressures affecting the marine environment, into an ecosystem-based approach to management. Finally, we reiterate the statement by Williams and Grosholz (2008) that NIS in coastal waters and estuaries should be managed with the same resolve as other major external stressors affecting marine ecosystems.

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