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Published in:
Journal of Environmental Management

DOI (link to publication from Publisher):
10.1016/j.jenvman.2021.113537

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Journal of Environmental Management 298 (2021) 113537

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

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ARTICLE INFO

Keywords:
Ecosystem services
Marine protected areas
Non-native species
Marine benthic habitats
Marine management and planning

ABSTRACT

Healthy and diverse marine ecosystems are a source of a whole range of ecosystem services (ES) and social, and economic benefits. To preserve and restore biodiversity, and sustain service supply, an international goal was set to protect at least 10 % of the global coastal and marine area by 2020. The goal has been achieved mainly through the designation of marine protected areas (MPAs). Whilst activities within the MPAs can be restricted to manage local pressures, the protected habitats and species are still exposed to stressors that originate outside MPA borders (e.g., non-native species, eutrophication). This study investigates the change in the protected stony reef habitat composition using underwater video observation in the coastal area of the eastern Baltic Sea known to be under the pressure of a non-native fish species. Further, assesses what the observed changes have meant for ecosystem functioning and ES supply adopting a tailor-made, expert judgement-based ES supply assessment method developed during the BONUS BASMATI project. The results suggest that the quality of the protected habitats in the case study sites has deteriorated and the transformation in species composition has altered ecosystem functioning and ES supply. The study highlights the importance of rich and diverse habitats for human wellbeing and livelihoods. Further, emphasises the need for more stringent MPA management plans, as well as a wider ecosystem-based approach to decision making in order to limit the impacts of stressors on marine ecosystems and secure ES supply.

1. Introduction

Healthy marine ecosystems are key to sustained ecosystem functioning, and the supply of ecosystem services (ES) and benefits (Rees et al., 2012; Hill et al., 2016). However, the marine environment is affected by various natural and anthropogenic pressures, which have, over time, cumulatively impacted the ecosystems (Halpern et al., 2019). This has resulted in the degradation, redistribution and in some cases even extinction of habitats and species (Lotze et al., 2006) resulting in change in ES supply (Worm et al., 2006; Culhane et al., 2019).

Numerous mechanisms have been devised and implemented around the globe to manage pressures on the ecosystems and to preserve and restore biodiversity and service supply (Maestro et al., 2019). One of the most popular has been the designation of marine protected areas (MPAs), such as the Natura 2000 network in Europe, which are nowadays considered as an integral part of conservation strategies (Evans, 2012; Hummel et al., 2019).

MPAs are place-based management tools used to regulate, in most cases restrict, human maritime activities in the vicinity of habitats identified as vulnerable, or of particular importance to the ecosystem (Jay, 2013; Rees et al., 2012; Norse, 2005) in order to preserve or restore the ecosystem (Kenchington and Day, 2011). For a long time, the sole aim of MPAs has been the protection of marine wildlife (Rees et al., 2012; Hill et al., 2016; Hummel et al., 2019). However, it has become widely acknowledged that as the sites of some of the most intact and biodiverse ecosystems, MPAs are a source of a whole range of social and economic benefits ensured by the supply of ES (Paoli et al., 2018), including cultural (e.g., an environment for recreation), regulating and maintenance (e.g., carbon sequestration) as well as provisioning services like fish for food due to the spillover effect (Potts et al., 2014). An ES approach is widely used to assess nature's contribution to human wellbeing through a summary of ecosystem structures, functions and their role in service supply followed by valuation of socio-economic benefits derived from the ES (Spangenberg et al., 2014).

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https://doi.org/10.1016/j.jenvman.2021.113537
Received 14 February 2021; Received in revised form 14 July 2021; Accepted 10 August 2021
Available online 20 August 2021

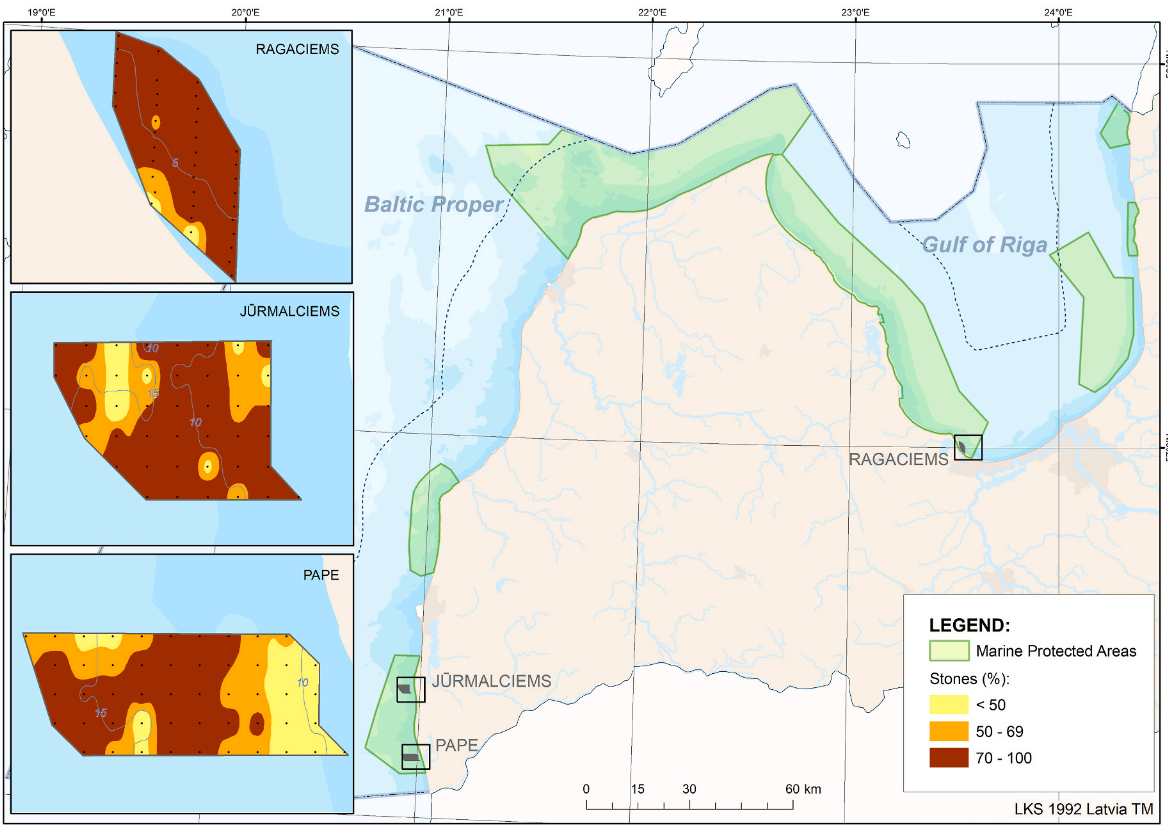

Fig. 1. Aerial distribution of the case study sites and observation point, and substrate type within the areas.

One of the main drawbacks of MPAs is that whilst the pressures originating within the protected areas are controlled, the habitats and species are still exposed to stressors which originate outside of the protected territory (Norse, 2005), including impacts of climate change, chemical (Robbins et al., 2017), and biological pollution (Simberloff, 2000). The successes and failures of MPAs as a spatial and temporal management tool are illustrated well by the experience of the world-famous Great Barrier Reef Marine Park (Maestro et al., 2019; Kenchington and Day, 2011; Day, 2002).

Even though the introduction and spread of a non-native species have been recognised as a significant threat to ecosystems on policy level (e.g., Bax et al., 2003; Molnar et al., 2008), MPA management plans rarely include guidelines for the management of non-native species and mitigation measures for making sure that they do not become invasive (Iacarella et al., 2019; Mačić et al., 2018; Ojaveer et al., 2015). One of the reasons for this could be the argument, that the protected ecosystems are diverse and therefore immune to invasions (Parreti et al., 2020). In the recent years, however, many (Giakoumi et al., 2016; Parreti et al., 2020 and references within) have disproved this by providing evidence that invasive non-native species have equally severe impacts on protected and unprotected habitats.

The effects of a non-native species are unique to an ecosystem (Katsanevakis et al., 2014; Hirsch et al., 2016; Catford et al., 2018). Some have been found to outcompete the native species, decrease biodiversity and have a widespread impact on ES supply (Pyšek and Richardson, 2010), while others - integrate into the ecosystem without significantly changing it or the services it supplies (e.g., Gozlan, 2008; Neves et al., 2020).

The round goby (*Neogobius melanostomus,* Pallas 1814), a demersal benthivorous fish species (Cross and Rawding, 2009), is one of the most widespread and successful non-native marine fish species in North America and Europe (Ojaveer et al., 2015; Pennuto et al., 2012). Originating from the Pont-Caspian region, the goby has particularly favours the brackish waters and since its first sighting in 1990 in the Gulf of Gdansk (Skóra and Stolarski, 1993), it has spread to other coastal areas of the Baltic Sea (Ojaveer et al., 2015).

The presence of the round goby has had a noticeable impact on the coastal ecosystems in the region (e.g., Almqvist et al., 2010; Henseler et al., 2021). It has become a part of the local food web – prey for some predatory fish and birds (Kraufvelin et al., 2018; Oesterwind et al., 2017) and has increased competition for food and habitat, impacting the recruitment levels and stocks of flounder and turbot (Karlson et al., 2007; Järv et al., 2011; Ustups et al., 2016). At the same time, the goby has become a target species and a source of income for some local fishers (Ojaveer et al., 2015).

The goby is an opportunistic feeder with a diet that consists of various organisms including bivalves, crustaceans and fish eggs (Skóra and Rzeznik, 2001; Kornis et al., 2012). Due to its feeding habits and preferences, the goby has been found to reduce the abundance of its prey species and has been identified as the key driver of reduction in mussel beds in the eastern Baltic region (Behrens et al., 2019; Skabeikis et al., 2019). Further, it has the capacity to alter benthic community structures and reduce ecosystem functioning by negatively affecting species with traits responsible for ecosystem processes (Henseler et al., 2021).

While the nature and degree of its impact may be context dependent (Henseler et al., 2021), all this evidence suggest the round goby's feeding habits and preference for hard substrate habitats may be putting protected, hard bottom benthic habitats such as stony reefs at risk.

The aim of this study is to assess the change in the composition and ecosystem functioning of the stony reefs on the coast of the eastern Baltic Sea and estimate ecosystem service supply. To achieve this, three case study sites situated within MPAs in the marine waters under the Latvian jurisdiction were studied. The chosen sites represented the typical types of the stony bottom reef habitats and were surveyed prior and post the spread of the round goby in the area.

The materials and methods are presented in chapter 2, followed by chapter 3 describing the results of the two-stage assessment. The results reveal that the two most significant drivers of change in the area – non-native species and eutrophication, have affected the native, protected habitats in a variety of ways, thus altering the services they supply. This leads to the discussion and conclusion in chapter 4 and 5, calling for more careful consideration of the risks posed by non-native species in MPA management strategies.

2. Material and methods

The species and structures of an ecosystem determine its capacity to supply services, therefore the state of an ecosystem gives an insight into the services it supplies. To estimate the effects of the goby on the ecosystem, the changes in habitat composition within the case study sites were assessed. Then, an assessment of ecosystem service supply was carried out following the method put forward in Armoškaitė et al. (2020). The steps taken to assess the environmental change and the change in service supply are described in detail in the sections following

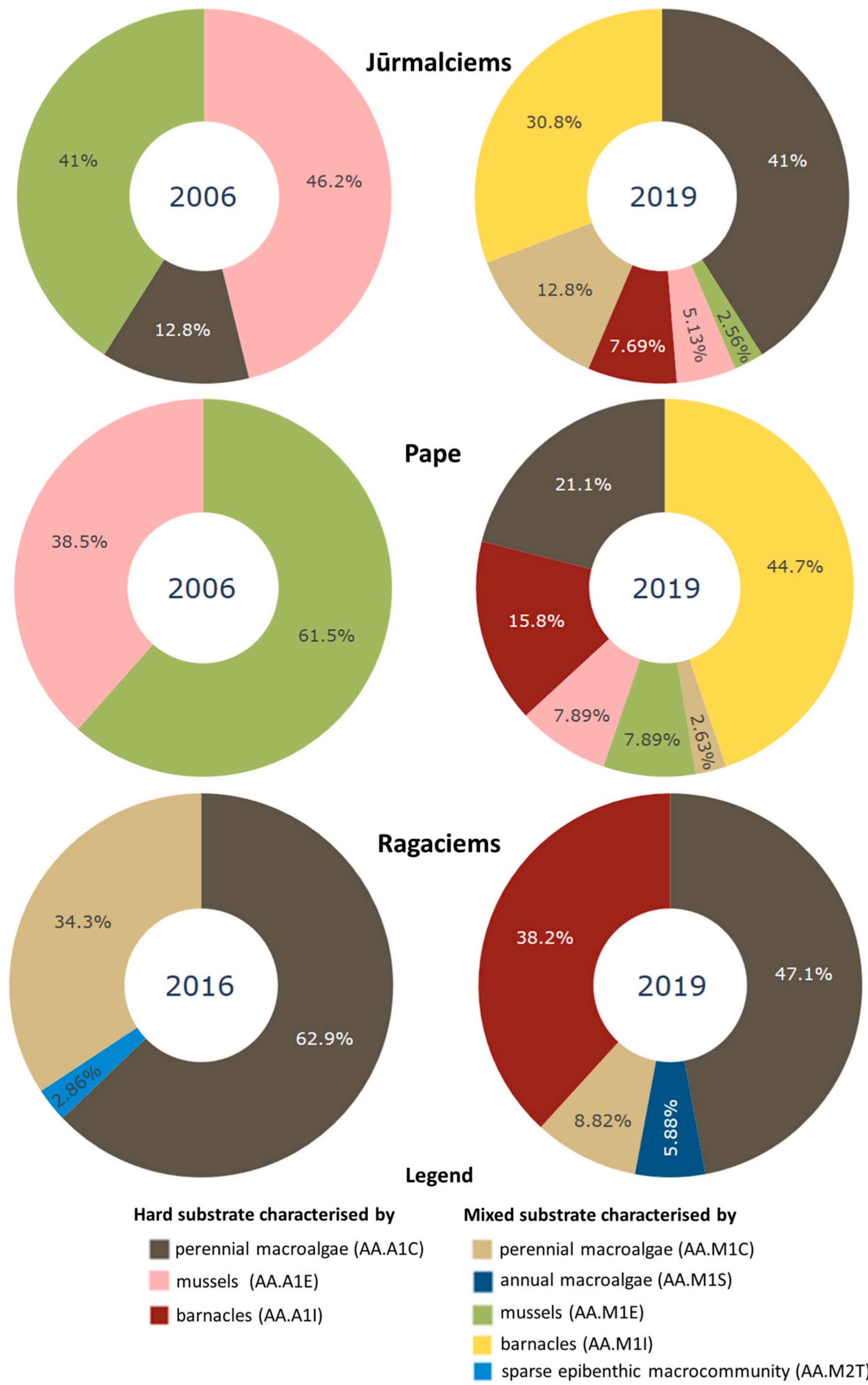

Fig. 2. Change in benthic photic habitat composition in the case study sites. Habitats classified according to the HELCOM Underwater biotope and habitat classification system (HELCOM, 2013a, 2013b). Habitat code indicated in brackets.

Table 1
Ecosystem functions performed and services supplied by the habitats found in the case study sites. Habitats classified according to the HELCOM Underwater biotope and habitat classification system (HELCOM, 2013a, 2013b). Ecosystem functions, services and codes adopted from Armoškaitė et al. (2020).

Habitat types	Ecosystem functions										Ecosystem services				
											Regulating and maintenance				
	Spawning & nursery habitats, benthic	Spawning, nursery & feeding habitats, pelagic	Refuge/ shelter habitats	Primary production, benthic	Primary production, pelagic	Fish feeding grounds	Filtration of suspended matter	Microbial transformations	Transport of materials & dispersal	Accumulation of materials	Nutrient regulation (by denitrification)	Nutrient regulation (by N, P burial)	Nutrient regulation (by nutrient incorporation in biomass)	Nutrient regulation (by N assimilation)	Hazardous substances accumulation & transformation
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	RM1	RM2	RM3	RM4	RM5
Hard substrate characterised by															
perennial macroalgae (AA.A1C)	x		x	x			x						x		x
mussels (AA.A1E)			x			x	x						x		x
barnacles (AA.A1I)			x				x						x		x
Mixed substrate characterised by															
perennial macroalgae (AA.M1C)	x		x	x			x	x			x		x		x
annual macroalgae (AA.M1S)	x		x	x				x			x		x		x
mussels (AA.M1E)			x			x	x	x			x		x		x
barnacles (AA.M1I)			x					x			x				x
sparse epibenthic macro-community (AA.M2T)			x					x			x				x
Pelagic															
Photic (AD. N)		x			x			x	x		x		x	x	x
Aphotic (AE. N)		x						x	x		x		x		x

Ecosystem services																
Regulating and maintenance		Provisioning									Cultural					
Physicochemical retention of pollutants	Carbon sequestration	Wild algae	Plant energy	Materials from algae	Wild fish, pelagic-herring	Wild fish, pelagic-sprat	Wild fish, benthic flounder	Wild fish, benthic-cod	Wild fish, benthic-round goby, eelpout	Fishmeal	Water environment for recreation	Water environment for science & education	Water environment for cultural & historical heritage	Water environment for spiritual experience	Existence of habitats & species	Water environment for enjoyment of seascape
RM6	RM7	P1	P2	P3	P4	P5	P6	P7	P8	P9	C1	C2	C3	C4	C5	C6
Hard substrate characterised by																
	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	×				×	×	×	×	×	×	×	×	×	×	×	×
	×				×	×	×	×	×	×	×	×	×	×	×	×
Mixed substrate characterised by																
	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×
	×	×	×	×	×		×	×	×	×		×			×	×
	×				×	×	×	×	×	×	×	×	×	×	×	×
	×						×	×	×	×		×			×	×
	×						×	×	×	×		×			×	×
Pelagic																
	×				×	×		×		×	×	×	×	×	×	×
	×				×	×		×		×	×	×	×	×	×	×

the study site description.

2.1. The study site description

Stony reefs are one of the most prominent and ecologically significant habitat types in the eastern Baltic Sea. In terms of structure and composition, stony reefs are an area of hard substrate (rocks, boulders and pebbles) surrounded by patches of sand (HELCOM, 1998; Supplementary Figs. 1 and 2). They are biologically rich, therefore, considered as biodiversity hotspots and protected under the European Habitats Directive (Council Directive 92/43/EEC). The most typical reef species is the mussel *Mytilus trossulus,* which is often accompanied by other macrofauna, e.g., bivalves, bryozoa, crustaceans, and benthic fish. In the euphotic zone reefs also host a diverse macroalgae community consisting of red algae (*Furcellaria lumbricalis, Coccotilus truncatus*), brown algae (*Polysiphonia* spp*, Batersia arctica*) as well as different types of green macroalgae (Torn et al., 2017; HELCOM, 2013a).

The mussel beds and perennial red algae like *F. lumbricalis* on the hard substrate provide further habitat structure and shelter and host additional species (Bucas, 2009). Combined mussels and perennial algae provide the essential spawning grounds for most of the regionally commercially important fish species, such as herring (Šaškov et al., 2014). Further, *M. trossulus*, due to its filtering ability, improves the water transparency in Baltic Sea coastal areas (Schröder et al., 2014).

The aim of the majority of the MPAs in Latvia, according to the MPA management strategies, is to preserve the state of stony bottom reef habitats and the ecological functions they perform at a level favourable for species that inhabit them. The three case study sites selected are situated within MPAs in the Latvian national marine waters and are monitored under the Latvian national monitoring programme (Fig. 1). Two out of the three sites (Jūrmalciems and Pape) are situated in the MPA "Nida-Pērkone" on the open Baltic Sea coast. The third site (Ragaciems) is in the MPA "Western coast of the Gulf of Riga". At the time of designation, around 61 % of the MPA "Nida-Pērkone" and 15 % of "Western coast of the Gulf of Riga" were classified as stony reefs.

The case study sites were selected based on data from the initial observations to represent a gradient of proportion between mussel and algae habitats, i.e., only mussel and no algae habitats in Pape, predominantly mussel but also some algae habitats in Jūrmalciems, and predominantly algae and close to no mussel habitats in Ragaciems. They are representative of the stony reef habitats as they are primarily made up of hard substrate e.g., Pape (78 %), Jūrmalciems (92 %) and Ragaciems (98 %) (Fig. 1).

The invasive, non-native species – the round goby, was first detected in the Latvian annual fish catch in 2006 (Latvian Fisheries Yearbook, 2014). At that time, the catch estimates suggest, the round goby population was confined to a few specific areas. However, by 2013 the goby had spread across to the Baltic Proper and was evenly distributed along the Latvian coast of the open sea and began appearing in several areas in the Gulf of Riga (Latvian Fisheries Yearbook, 2014).

The goby population was relatively small and stagnant for the first few years but began to rise in 2013–2014 (Ustups et al., 2016; Latvian Fisheries Yearbook, 2014). By 2018, the round goby's annual catch had increased from 25.9 tonnes in 2013 to 1112.9 tonnes. Over the years, a significant part of the catch has been constantly caught in the open Baltic (Institute of Food safety, Animal Health and Environment "BIOR," 2019).

2.2. Assessment of habitat composition

The assessment of the underwater habitats before and after the spread of the round goby was based on the observations made from underwater video recordings captured on a 500 m-to-500 m grid (Data available upon request). The first video recordings of the site in "Western coast of the Gulf of Riga" and the two sites in "Nida-Pērkone" were made in 2016 and 2006, respectively. All sites were then revisited in 2019.

Using the video data, the projective cover was analysed and categorised into habitat types according to substrate type (e.g., percentage of large boulders, boulders, pebbles, cobbles, gravel, and sand), and benthic community type based on coverage of all visually identifiable species, including species of perennial and annual algae (e.g., *Furcellaria lumbricalis, Coccotylus truncatus, Battersia* spp., *Polysiphonia* spp., *Ceramium* spp., *Cladophora* spp.), mussels (*Mytilus trossulus*), barnacles (*Amphibalanus improvisus*) and erect moss animals (*Cordylophora caspia*). The high level of detail captured in the video made it possible to classify the habitats according to the dominance of particular species or species complexes (Level 5) following the HELCOM Underwater Biotope and Habitat Classification System (HELCOM, 2013a, 2013b).

2.3. Assessment of ecosystem functioning and ecosystem service supply

Six separate assessments of ecosystem functioning, and service supply were conducted – two for each case study site, to evaluate the impacts of habitat change.

As described in Armoškaitė et al. (2020), the assessment method employed follows the capacity matrix approach and is structured according to the ES cascade framework (Potschin and Haines-Young, 2016), which links ecosystem components to functions, and the services they supply. Expert knowledge is used to quantitatively estimate the relative contribution of species, habitats in ecosystem functioning, and the contribution of functions in the supply of services in percentage values, which are interpreted as weights used to calculate the overall relative importance of habitats in service supply.

Previously, all 24 types of habitats found in the Latvian marine waters were linked to 10 ecosystem functions and 22 ES (7 regulating and maintenance, 9 provisioning and 6 cultural) (Armoškaitė et al., 2020) identified using the Common International Classification of Ecosystem Services (CICES) v.5.1. In this study, only the habitat types observed at the case study sites and associated linkage chains were selected. Pelagic habitats were also included in the assessment since the water column, is essential for the survival and mobility of benthic species.

Given the geographical overlap of the case study location and the timing of the studies, the weights defined during the elicitation exercise in Armoškaitė et al. (2020) were employed in the assessment presented in this paper. Because they described the interrelations in a good environmental state, they were used as the reference point, or the capacity of the ecosystem to supply services before the spread of the round goby.

Subsequently, the outlined steps were taken to estimate the change in ecosystem functioning and services supply.

Firstly, the importance of the ecosystem functions (*FI*) in the supply of each service, habitats (*HI*) in the performance of each ecosystem function, and species (*SI*) in the formation of every habitat were calculated:

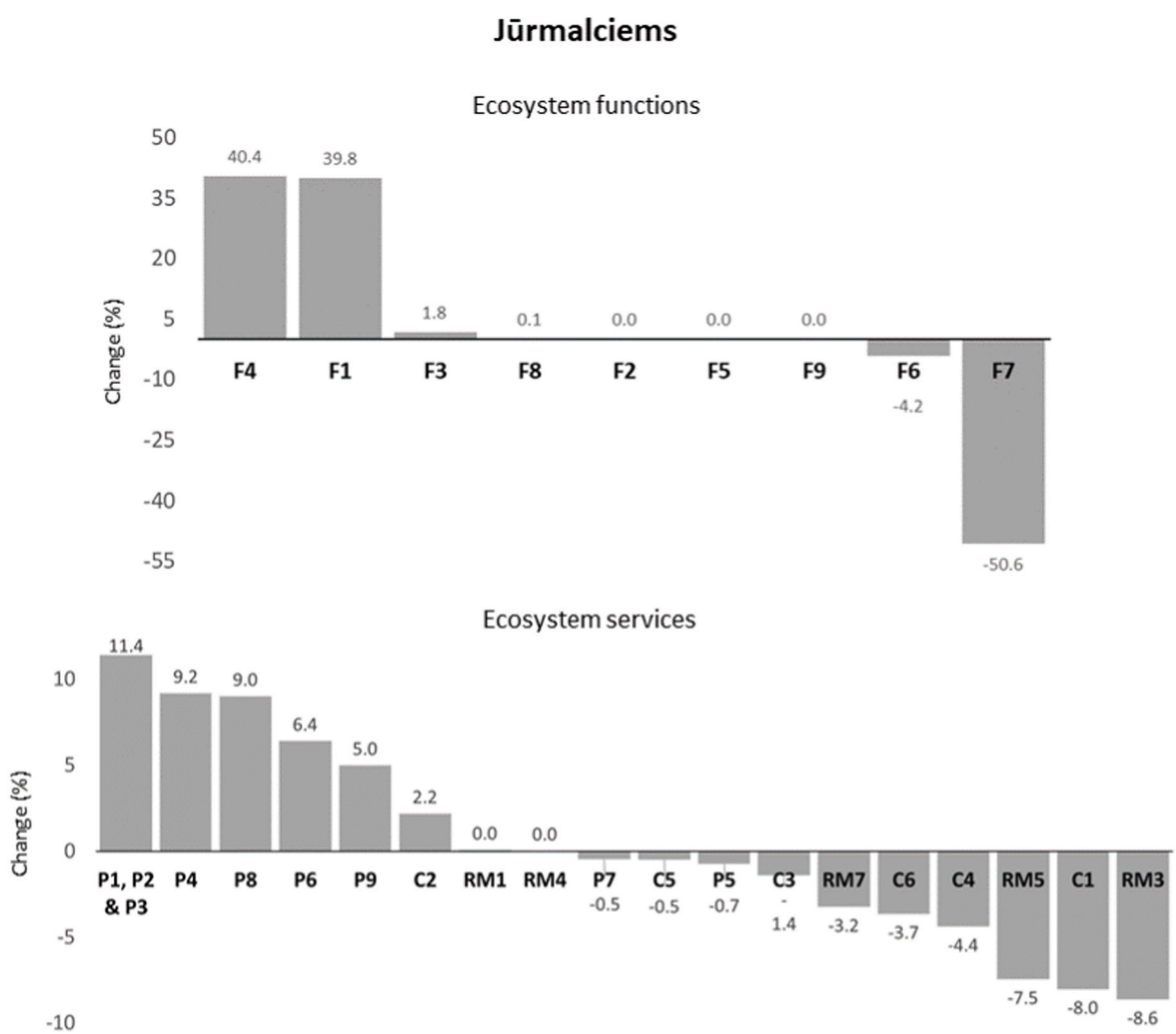

Fig. 3. Change in ecosystem functioning and service supply in Jūrmalciems (%).

$$FI = fw$$
$$HI = \frac{hw}{\Sigma hw\ x\ \Sigma FI} \quad (1)$$
$$SI = \frac{sw}{\Sigma sw\ x\ \Sigma HI}$$

fw is the expert ascribed weight defining the relationship between a single service and an ecosystem function, *hw* is the weight describing the relationship between a function and a habitat, *sw* is the weight describing the relationship between a habitat and a species.

To estimate the impacts of change in the environmental conditions or the status of species or habitats on the ecosystems' capacity to supply services, inverse weights were calculated for each one of the original weights. Inverse weights describe a species (*isw*) importance in habitat formation, habitat (*ihw*) importance in function performance and the importance of each function (*ifw*) in the supply of services:

$$isw = \left(\frac{SI}{\Sigma SI}\right) \times 100$$
$$ihw = \left(\frac{HI}{\Sigma HI}\right) \times 100 \quad (2)$$
$$ifw = \left(\frac{FI}{\Sigma FI}\right) \times 100$$

The sum of the values defining the importance of each species (SI), habitats (HI) and functions (FI) and the inverse weights were then used to work out the relative contribution of each species (*SRC*), habitat (*HRC*) and function (*FRC*) in the ES supply:

$$SRC = \frac{\Sigma SI \times isw}{100}$$
$$HRC = \frac{\Sigma HI \times ihw}{100} \quad (3)$$
$$FRC = \frac{\Sigma FI \times ifw}{100}$$

The FRC value indicates the level of service supply. ***100*** is the contribution of species, habitats, and functions at full capacity in a good environmental state. Change in capacity is reflected in this value. It is altered according to change in biomass or spatial distribution of the species or habitat within the studied area. In this case, it was changed to reflect the proportional variation in the spatial distribution of habitats in the case study sites estimated using the methods outlined in section *2.2 Assessment of habitat composition.*

The final step was to estimate the difference in ecosystem functioning and services supply between the different time frames. To do this, the *FCR* and *HRC* values for years 2006 and 2016 were deducted from year 2019 for each ecosystem function and service.

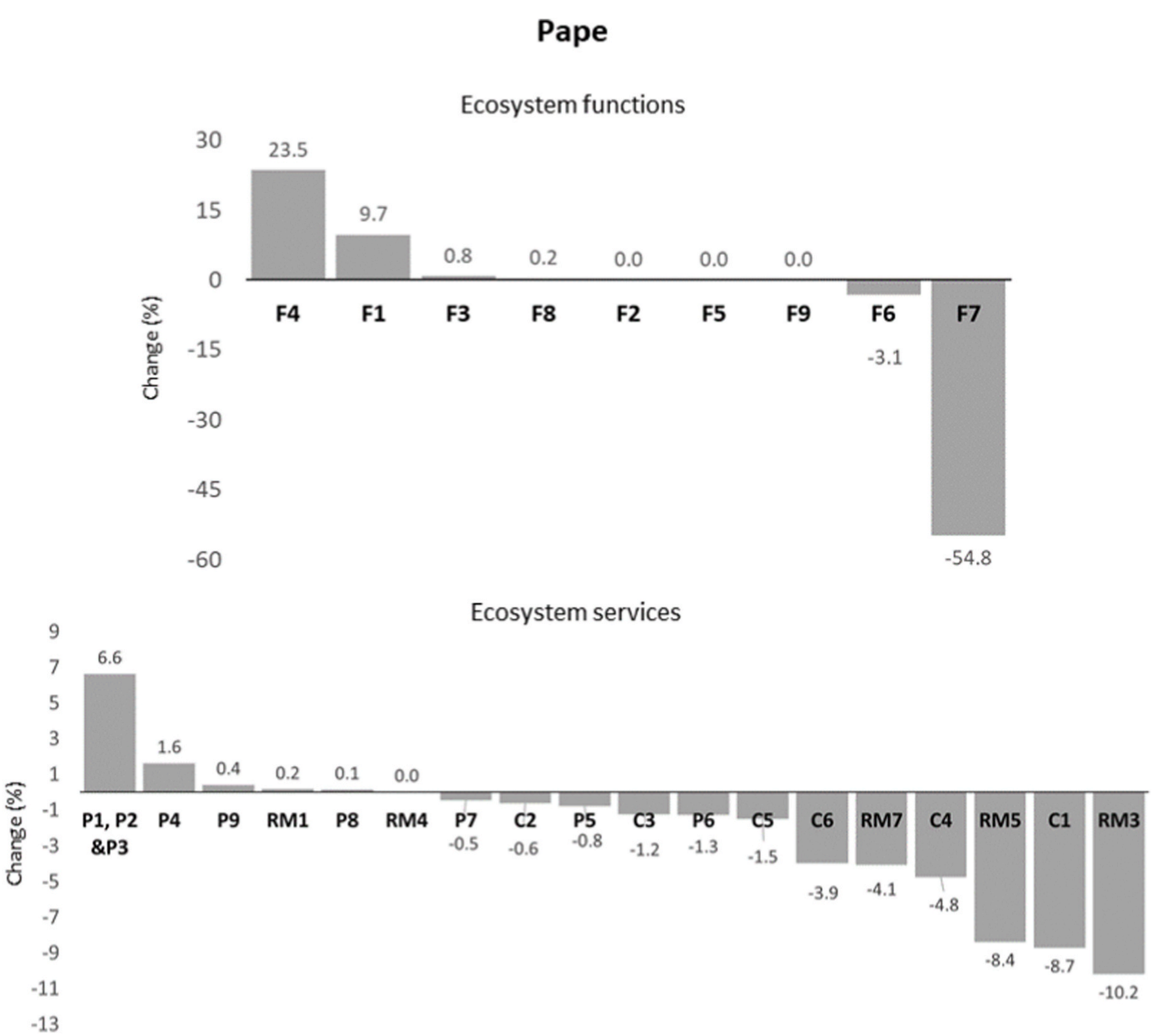

Fig. 4. Change in ecosystem functioning and service supply in Pape (%).

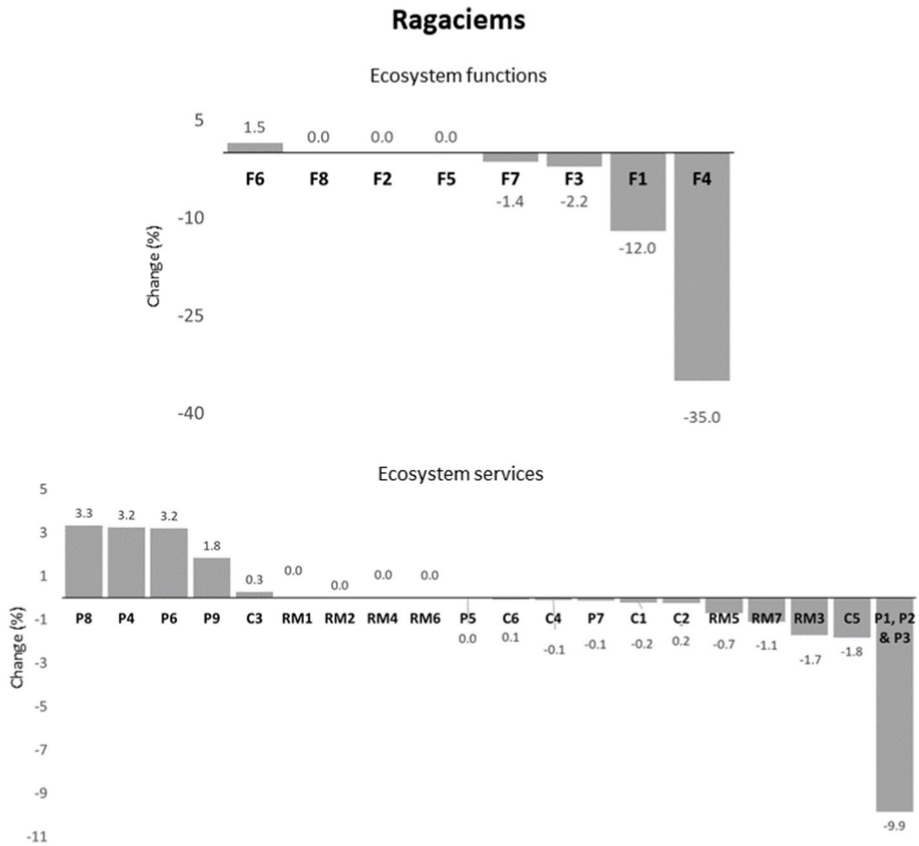

Fig. 5. Change in ecosystem functioning and service supply in Ragaciems (%).

3. Results

3.1. Habitat composition

According to the results of the video surveys conducted in 2006, the hard substrate surface was predominantly covered by the dense mussel *Mytilus trossulus* communities (Fig. 2; habitat types AA.A1E and AA.M1E) in Pape and Jūrmalciems. Perennial algae habitats (type AA.A1C) were either very sparse (Jūrmalciems), or not observed at all (Pape). In Ragaciems, in 2016, however, perennial algae habitats (AA.A1C and AA.M1C) dominated the surface of the hard substrate (Fig. 2), whilst sparse epibenthic macro community habitat (AA.M2T) accounted for a minor proportion of the area.

The more recent benthic habitat surveys conducted in 2019, indicate that there has been a significant change in seabed coverage composition in Pape and Jūrmalciems. The area, which was covered by mussel beds in 2006, is now primarily dominated by epibenthic crustacea (*Amphibalanus improvisus*) in Pape, and perennial algae (mostly *Furcellaria lumbricalis*) in Jūrmalciems (Fig. 2).

In the case study site Ragaciems, the change in habitat structure was much less dramatic than in Pape or Jūrmalciems and of a different nature. The extent of perennial algae habitat cover has decreased since 2016, and the vacated area has mostly been taken over by epibenthic crustacea (Fig. 2). Interestingly, in 2019 annual algal habitats (AA.M1S) were only detected in Ragaciems and neither of the other case study sites.

3.2. Ecosystem functioning and service supply

The benthic habitats in the case study sites were found to perform six different ecosystem functions (EF), and 19 regulating and maintenance, provisioning and cultural services (see Table 1).

The ecosystem functioning and services supply comparison study showed that no functions and services were lost due changes in habitat composition (see Figs. 3–5) and the functions solely performed by pelagic species (F2, F5 and F9) were unaffected. A more detailed breakdown of the assessment results for each case study sites follows.

The supply assessment results show that the hard-bottom benthic community found in the Jūrmalciems case study site performed nine EFs and supplied 18 ESs (Fig. 3) back in 2006. The loss of the mussel (*Mytilus trossulus*) seabed cover resulted in a drastic decrease in the ecosystem's ability to *Filtrate suspended matter*. Further, the increase in perennial algae cover enhanced the ecosystems' capacity to provide *Spawning & nursery habitats &* perform *Primary production*.

The alterations in ecosystem functioning caused varying degrees of changes in ES (Fig. 3). On average there has been an overall 5.66 % increase in supply of provisioning services, 2.6 % loss in the supply of cultural ecosystem services, and a 3.86 % loss in regulating and maintenance services in Jūrmalciems.

The same set of EF performed in Jūrmalciems was and continues to also be performed in Pape. Besides, just like Jūrmalciems, Pape has suffered a loss in mussel cover resulting in a large drop in the EF *Filtration of suspended matter* (Fig. 4). However, the mussel beds in Pape were replaced by barnacle (*Amphibalanus improvisus*) colonies and only to a lesser degree by perennial algae. Because of this, the increase of EF *Spawning & nursery habitats & Primary production* in the benthic environment in the Pape case study site is only half of that observed in Jūrmalciems.

The change in habitats and EF performed within the Pape case study site are also reflected in levels of ES supply (Fig. 4). Like in Jūrmalciems, the most significant change in supply was seen in services *Nutrient regulation (by nutrient incorporation in biomass)*, *Hazardous substances accumulation & transformation*, and *Water environment for recreation*. The ES like *Wild plants, Plant energy* as well as *Materials from algae* associated with the presence of algae demonstrated positive change, although to a lesser degree than that observed in Jūrmalciems.

Overall, the supply of regulating and maintenance services in Pape dropped on average by 4.5 %, and of cultural ecosystem services by 3.5 %. Provisioning services, on the other hand, increased on average by 1 %. The increase in provisioning services was mainly due to the increase in the supply of *Wild plants, Plant energy & Materials from algae*. Other provisioning services saw insignificant levels of change, only a slight increase in the supply of *herring*, and a small decrease in the supply of *flounder*, *cod,* and *sprat.*

Unlike the other two sites, the EF provided by benthic habitats in Ragaciems were largely performed by perennial algae. The sharpest drop in Ragaciems ecosystem functioning has been in the benthic ecosystem's capacity to perform *Primary production* and provide *Spawning and Nursery habitats* due to the decrease in cover of perennial macroalgae (Fig. 5). Algae cover can be seen to be replaced by epibenthic crustacea resulting in a slight increase of the sites' role as a *Fish feeding ground*.

The changes in habitat composition and the associated EF in Ragaciems have resulted in an overall drop in ES supply (Fig. 5). The highest decrease was observed in ES associated with perennial algae, e.g., *Wild plants, Plant energy, and Materials from algae*. On average, the supply in regulating and maintenance services has decreased by 0.5 % and that of cultural ecosystem services by 0.4 %. The supply of provisioning services, on the other hand, has increased by 0.2 %. The increase can be attributed to the slight increase of a select few service supplies including *herring, flounder, goby, eelpout* as well as *fishmeal.*

4. Discussion

The stony reefs in the southern regions of the Baltic have been devastated by bottom trawling and material extraction, while the impacts of invasive species, particularly the round goby, and eutrophication have been highlighted as the most significant pressures on the coastal habitats on the eastern coasts (Kraufvelin et al., 2018). Although it could be argued that the effects of eutrophication will cease in the future thanks to the overall improvement of the Baltic Sea marine environment due to policies implemented outside the confines of the MPA, the effects of non-native species are unlikely to stop, as once established non-native species are very difficult to eradicate (Ojaveer et al., 2015).

Like many others (Iacarella et al., 2019), the MPAs within which the case study sites are situated neither have management plans outlining strategies for prevention of the introduction and the spread of non-native species, nor mitigation measures. However, given the degree of change observed in the case study sites it is fair to say that this needs to change and the complexity of habitat responses to combined pressures like introduced non-native species, as well as eutrophication, should be reflected in the management strategies if MPAs are to be effective.

Quite often, non-native species turn out to be invasive and create undesirable effects because they do not have natural enemies in the newly invaded territory or the species, which could act as a natural controlling element, are suppressed by anthropogenic activities. Fishing has been presented as a means to manage the goby population size, however fishing restrictions within MPAs may be limiting the effectiveness of this approach (Behrens et al., 2019). The best management strategy, when it comes to non-native species, is the prevention of introduction (Iacarella et al., 2020; Otero et al., 2013). Since it is hard to prevent migration of species from one basin to another if there are no natural barriers a combination of early warning systems and adaptive management would be invaluable to safeguard sensitive species (Giakoumi et al., 2018, 2019; Agardy et al., 2011), the food web, ecosystem functioning, and service supply, further highlighting the importance of monitoring within MPAs (De Santo, 2013). In this instance, due to the lack of protection and mitigation measures, the favourable feeding conditions for seabirds wintering in the area created by the abundance of mussels have been devastated (Skabeikis et al., 2019).

The dramatic decline of the mussel population was expected at the onset, since the mussel *Mytilus trossulus* is one of the preferred food sources of the round goby (Wiegleb et al., 2018), as was the increased presence of the competitive species replacing the mussels. However, the differences between the sites in Pape and Jūrmalciems in species proportions were surprising. Both sites are within photic limits sufficient to support the development of algae. Therefore, it was anticipated that perennial algae would replace the mussels. However, a substantial proportion of the vacated area with no detectable depth dependency in Pape has been taken up by epibenthic crustacea habitats dominated by the barnacle - *Amphibalanus improvisus.*

Amphibalanus improvisus is highly tolerant of eutrophication and its effects (Leppäkoski, 1999), which suggests that Pape has experienced the effects of eutrophication at a higher degree than Jūrmalciems. This assumption is also consistent with results of the monitoring observations from the Latvian National Monitoring programme (Latvian Institute of Aquatic Ecology, 2018). However, the data obtained during this study is insufficient to verify that the differences in eutrophication levels between the two sites is the main reason for the variation in algae and crustacean cover. To confirm the observations further study of greater scope focused on understanding the role of eutrophication in determining species cover should be carried out.

The case study site Ragaciems was primarily selected as an area where there were no or very little mussel beds and hence with little expectation to detect the presence or the environmental impact of round goby. As no changes have been observed, which could be linked to the round goby, the assumption has been confirmed. The decline of perennial algae in the area and the subsequent repopulation by epibenthic crustacea, as well as annual algae, is consistent with effects manifested by increasing eutrophication. In comparison to Jūrmalciems and Pape, the results of the ES supply assessment for Ragaciems are much grimmer, as the loss in service supply is not regained with an increase in other services. This illustrates the dire effect of eutrophication on the marine environment and its capacity to support the livelihoods of people.

The assessment allows to at least partially substantiate claims regarding habitat degradation, as it demonstrates how the loss of one ecosystem component or habitat presents an opportunity for another to increase presence and how this influences the type and level of services supplied by the ecosystem. In the case study sites, for instance, the seabed left empty by the shrinking mussel (*Mytilus trossulus)* population has been re-populated either by barnacles (*Amphibalanus improvisus)* or perennial algae. Neither of which filtrate suspended matter or offer similar EFs, which would support the supply of the services associated with mussels.

In areas populated by barnacles, there has been an overall decline in ecosystem functioning. However, perennial algae are the key suppliers of provisioning services including *Wild fish, benthic – round goby, eelpout,* and *Wild fish, pelagic – herring,* and an increase in algae cover has resulted in a shift from an ecosystem that was once mainly filtering suspended matter, to an ecosystem responsible for primary production, and spawning, and nursery habitats. This further supports earlier findings that the round goby, as a non-native species, may not necessarily have an adverse effect on the ES supply (Giakoumi and Pey, 2017) and in some cases may increase the supply of certain services (as described in the review by Katsanevakis et al., 2014).

The results also demonstrate that ES supply changes over time and suggest that assessments need to be carried out on a regular basis to reflect the social and environmental systems and provide reliable evidence for decision making. Moreover, the results remind that supply assessments rely heavily on the methods of data collection and analysis used to describe the state of the ecosystem (Armoškaitė et al., 2020). Albeit extensive and widely used, the HELCOM Underwater Biotope and Habitat Classification System, (HELCOM, 2013a, 2013b), from our experience, fails to acknowledge instances where observations of some key species have been made, yet the habitat is so severely otherwise degraded, that it is on the cusp of transformation into a new type of biotope.

The EF and ES assessment technique presented here is one of many approaches used to describe the link between the natural and social systems and the consequences of environmental change on people (Crossman et al., 2012). While some use absolute metrics such as energy in emergy analysis to describe the biophysical flow of services and translate it into comparable, socio-economic units (Paoli et al., 2018; Vassallo et al., 2017), the approach presented here provides the opportunity to describe the biophysical functioning and ES flow in percentages derived from expert judgment and field data. The results presented here provide the groundwork for future assessments of the consequences of environmental change in social and economic terms, which is advantageous as the repercussions on human wellbeing and livelihoods are far better illustrated through assessment of benefits – their value and distribution (Bateman et al., 2011; Frederiksen et al., 2021). Every single ES provides multiple different benefits including health, safety, and employment, which can be valued in monetary and non-monetary terms (von Thenen et al., 2020). A full-scale ES supply assessment for the entirety of the MPAs discussed in this study, and a benefit valuation study would be highly encouraged to depict the difference in the type, and value of benefits that the benthic habitats supply. The results of such assessments could support evaluation of MPA effectiveness and improve decision-makers' understanding of the socio-economic implications, including issues of equity, due to changes in the marine ecosystem, service, and benefit supply.

5. Conclusion

The results presented in this study describe how the change in the composition of the protected, stony reefs in the case study sites on the Latvian coasts of the eastern Baltic Sea has affected the ecosystem functioning and service supply, including a drop in regulating and maintenance, and cultural services, and increased provisioning service supply.

While the goby is seen as the primary stressor affecting the composition of stony reef habitats in the Baltic Proper and the main driver of change, the devastating effects of eutrophication are clearly illustrated by the results of the assessment of the case study site situated in the Gulf of Riga. On the upside, the results also suggest that whilst stressors, like invasive non-native species or enrichment of nutrients, can cause severe changes in species composition, this does not necessarily result in complete degradation of habitats. Further, as it is demonstrated in this study, while the decrease in the abundance of a key species may result in a dramatic drop in the performance of some ecosystem functions the free space left by a shrinking population also creates space for another, in some cases replacing the lost services with new ones.

However, the results also support previous findings that the effects of a non-native species are unique to the ecosystem and cannot be easily predicted, therefore positive outcomes are not a given. To protect the valuable ecosystem integrity and ensure a sustainable service supply, it is recommended that the risks of introduction and spread of non-native species are considered in MPA management strategies and managed through early warning systems and adaptive management.

Author contributions

Aurelija Armoškaitė: conceptualisation, methodology, formal analysis and investigation, visualization, writing - original draft, writing - review & editing. **Juris Aigars**: conceptualisation, methodology, writing - original draft, writing - review & editing. **Ingrida Andersone:** conceptualisation, methodology, formal analysis and investigation, writing - original draft, writing - review & editing. **Henning Sten Hansen**: conceptualisation, writing - review & editing. **Lise Schrøder**: conceptualisation, writing - review & editing. All authors have approved the final article. **Solvita Strake**: conceptualisation, analysis, writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to thank the anonymous reviewers for their constructive feedback and Sandra Sprukta (Latvian Institute of Aquatic Ecology) for her GIS expertise in producing Fig. 1. The study has been supported by the "Baltic Sea Spatial Planning for sustainable Ecosystem Services" (BONUS BASMATI) project and the Latvian National Council of Science Grant "Role of invasive species *Neogobius melanostomus* in the functioning of Baltic Sea underwater protected habitats" (Nr. lzp-2019/1-0337). BONUS BASMATI has received funding from BONUS (Art. 185), jointly funded by the European Union, Innovation Fund Denmark, Swedish Research Council Formas, Academy of Finland, Latvian Ministry of Education and Science and Forschungszentrum Jülich GmbH, Germany.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113537.

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