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A fishing ground benthic ecosystem improved during the economic crisis

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Fisheries have global socioeconomic and ecological effects. Long-term ecological studies could be beneficial to ecosystem approach management and biodiversity conservation, however, they are rare. In this study, the impacts of bottom trawling on a traditional fishing ground in the Eastern Mediterranean were addressed and an improvement in diversity metrics and ecological quality status were detected and ascribed to the Greek economic crisis. After 18 years, there was a modest increase in species richness, total abundance, and ecological status in the unaffected zone and more pronounced improvement in the trawled zone pointing at a possible link to a decrease in fishing effort. This upturn emphasized the strong link between financial activities and ecology. The present study underlines the multiple and variable effects of economy not only on countries and citizens but also on the environment and ecosystem conservation and management.

Keywords: ecological quality status; economic crisis; long-term study; macrofauna; trawling activity.

Introduction

Mankind has always relied on the oceans for food supply, employment, recreation, and waste disposal. As a result, overexploitation, eutrophication, and pollution are just a few of the impacts of anthropogenic activities affecting the marine environment (Halpern *et al.*, 2008). Fisheries have global socioeconomic and ecological effects. In many countries, the fishery sector is associated with their tradition and culture (FAO, 2015) and is responsible for a considerable portion of employment, with small- or large-scale businesses working not only on fish captures but also on fish processing, marketing, and distribution (Natale *et al.*, 2013; Teh and Sumaila, 2013). At the same time, fisheries constitute one of the main types of marine resource exploitation worldwide resulting in biodiversity loss as well as in changes in ecosystem functioning and the supply of ecosystem goods and services (Jennings and Kaiser, 1998; Thrush *et al.*, 1998; Colloca *et al.*, 2017; Crespo and Dunn, 2017).

Bottom trawl fishing is widespread, covering large coastal and shelf areas in Europe (Eigaard *et al.*, 2017) and is considered to be a particularly strong anthropogenic disturbance to benthic communities and habitats (Collie, 2000; Jennings *et al.*, 2001). Nevertheless, trawling impacts are quite variable (Eigaard *et al.*, 2016). The impacts of bottom trawling range from negligible to severe, requiring long recovery times for benthic ecosystem (Kaiser *et al.*, 2006; Hinz *et al.*, 2009), this variability depends on the spatial and temporal distribution of fishing effort and on the environment where these impacts occur (Kaiser *et al.*, 2006; Hiddink *et al.*, 2017). In addition, fisheries are an important sector of economic activity, particularly for coastal and island communities, and as a result they are easily subject to financial problems that determine their status (Beddington *et al.*, 2007). Fish stocks, fuel prices, and competition with other sectors are only a few of the factors that affect fisheries economic vulnerability, while a significant amount of fisheries-dependent communities have been identified in the coastal European region (Pascoe, 2006; Natale *et al.,* 2013). In the context of an ecosystem approach, fisheries management has started to take into account this variability with the purpose of meeting conservation goals, avoiding overexploitation and achieving improved efficiency of the sector (Eigaard *et al.,* 2016). The success of such management is designated in terms of biological, economic, social, and political objectives (Beddington *et al.,* 2007).

The long-term effects of a human activity such as bottom trawling are usually difficult to determine in an area where there are multiple contributions from different sources of impacts. However, comparison of the current composition of marine communities with historical data can provide a basis for understanding the driving factors of the observed changes (Rumohr and Kujawski, 2000). Long-term ecological studies could be beneficial to an ecosystem approach to management and biodiversity conservation, providing valuable data that could support evidence-based decision making to policy makers and the general public (Lindenmayer *et al.,* 2012).

A suitable area for the assessment of the long-term impacts of trawl fishing is thought to be the fishing ground north of Crete (Eastern Mediterranean). This fishing ground is located in a relatively deep area (200 m) that is considered to be unaffected by other major anthropogenic impacts such as nutrient inputs or urban and industrial run-off pollution (Simboura *et al.,* 2016). In this context, it was assumed that long-term use of towed fishing gears will eventually result in long-term changes in benthic communities and the associated metrics and variables. Benthic indicators from the EU Water Framework Directive (WFD, 2000/60/EC) have been typically applied to address impacts of eutrophication and other pollution sources, and their response to bottom trawling are questionable (Gislason *et al.,* 2017). Nevertheless, some indicators such as the benthic quality index (BQI) and species density are negatively correlated to trawling intensity and consequently could elucidate chronic disturbance due to trawling (Gislason *et al.,* 2017).

A comprehensive dataset, containing benthic data from two sampling campaigns [data from Smith et al. (2000) and present study] with 18 years difference (1996–2014), with seasonal and replicated sampling within a traditional fishing ground and in adjacent reference (untrawled) areas, was used to identify whether there are significant changes in the benthic communities. Specifically, the objectives of this study were to assess changes in (i) benthic community diversity metrics and (ii) benthic ecological quality status, after 18 years, within the traditional fishing ground and in the adjacent reference (untrawled) areas.

Methods

Study area and sampling strategy

The study area is located north of Heraklion bay, Crete (south Aegean Sea) where a commercial trawl lane runs east–west at a depth of approximately 200 m. This trawling ground is exploited by fishers during the open season from October until the end of May every year. The sediment in the sampling area measured is characterized by high content of silt and clay (80%) with median grain size 0.01–0.02 µm. These values are similar to those reported by Smith et al. (2000) for the 1995–1996 sampling in this area.

In 1995–1996, Smith et al. (2000) collected monthly/bimonthly benthic samples from four stations. Two stations were exposed to fishing within the trawl lane (stations inA and inB) and two control stations were located on either side of the trawl lane (stations outA and outB) (Figure 1). The present sampling strategy was identical to that conducted by Smith et al. (2000) in order to minimize artefacts concerning experimental design. Specifically, recent sampling was carried out during two occasions, one at the beginning of the trawling season (November 2013) and one at the end (April 2014). At each station during both seasons, five replicates were taken for macrofaunal analysis, using the same gear, a 0.1 m^2 Smith-McIntyre grab. Macrofaunal samples were sieved *in situ* using a 0.5 mm mesh, fixed with 5% buffered formalin, stained with Rose Bengal and stored for further analysis. Samples were sorted by hand and benthic specimens were identified at the species level and counted. All scientific names were cross-checked, verified, and taxonomically updated using the Taxon Match tool of the World Register of Marine Species (WoRMS Editorial Board, 2018). Macrofaunal data obtained from the recent sampling events (November 2013 and April 2014) were compared to the results obtained from the study of Smith et al. (2000) in comparable periods of the year (1995–1996), in order to minimize the effect of seasonal changes.

Additional triplicate cores (5 cm of diameter) for surface sediment analyses (0–2 cm layer) were also collected, frozen and stored at −20°C. During the sampling, sediment temperature (T) and redox potential (Eh) were measured at the water–sediment interface by means of an electrode.

Laboratory analyses

Sediment samples were analysed for granulometry, Chl *a*, and organic matter concentrations. Sediment content was measured following the protocols by Gray and Elliott (2009). Chl *a* content was measured using a Turner fluorometer following extraction with 90% acetone (Yentsch and Menzel, 1963). The loss on ignition (LOI) method was used to determine the percentage of labile organic matter (LOM) in sediments. Organic material was determined as the weight loss of the dried sample after combustion for 16 h at 250°C (Loh *et al.,* 2008). In order to compare the organic carbon content (TOC) between the two sampling periods, the LOI values were divided by a factor of 2 to convert to TOC (Frangipane *et al.,* 2009).

Statistical analyses

Biodiversity metrics and ecological quality indices were calculated from the recent (2013–2014) and the historical (1995–1996) dataset, including species richness per sampling unit, total abundance per sampling unit, and benthic quality index at family level (BQI-family) (Dimitriou *et al.,* 2012). Among other benthic indices, the BQI-family was selected in an attempt to minimize possible artefacts originating from differences in species identification methodology between the two sampling periods.

Univariate data analysis [three-way analysis of variance (ANOVA)] was performed to test the variability in all variables among the factors year, season, and treatment. To check the assumptions of approximately normal data and homogeneity of variance, required for three-way ANOVA, the Shapiro–Wilk test and Levene's test were performed. When the three-way ANOVA indicated that there were significant differences within the dataset, Tukey's test was used as a *post-hoc* test between pairs of factors.

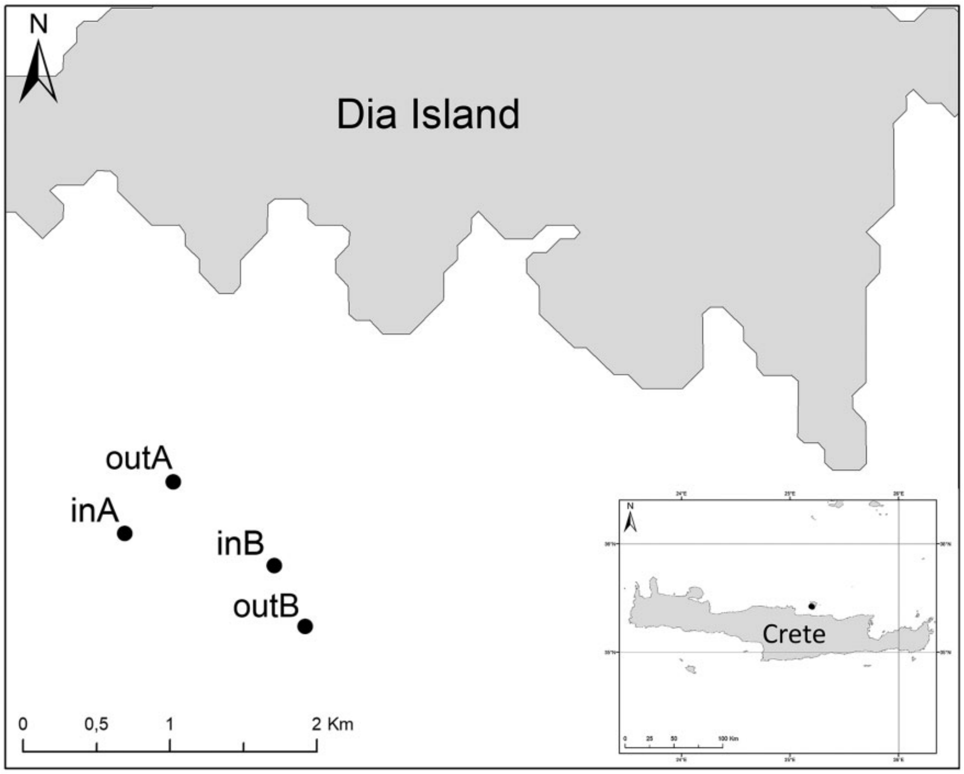

Figure 1. Map of the sampling stations. Black circles indicate the stations located in the trawled zone (inA, inB) and the control stations out of the trawled zone (outA, outB).

Estimation of fishing activity

After 2009, Greek legislation obliged fishing vessels over 15 m to carry vessel monitoring systems (VMS), from which spatial fishing activity could be assessed and trends in fishing effort estimated. As a result, fishing activity of trawlers was estimated as recorded days at sea. Before 2009, trawling activity was recorded on vessel logbooks sporadically and on a voluntary basis and therefore they could not be considered as comparable to VMS data. It must be also highlighted that before 2009 in Greece, fishing effort was expressed in landings, number of boats and boat tonnage (measured in gross registered tons, GRT) (Stergiou *et al.*, 2007).

VMS data, bottom trawl landings, and number of vessels were provided by the National Fisheries Data Collection Programme (EPSAD) (2017). The analysis of VMS data was based on methods developed by Kavadas *et al.* (2014). Briefly, speed thresholds for bottom trawlers were used to define the "fishing" activity. VMS readings of speed less than 4 knots were considered to correspond to "fishing". Fishing activity for a specific fishing rectangle covering the study area was expressed in number of fishing days. Trawl landings and number of trawlers referred to the region of Crete.

Semi-structured interviews with local fishermen were carried out at the port of Heraklion. The aim of the interviews was to identify trawling activity changes between the historical sampling period (1996) and the recent one (2014), and also to detect the possible reasons that led to these changes. The owners of the only two trawlers based in the port of Heraklion and traditionally using this fishing lane were asked to recount their trawling activities in the study area over the past 18 years (from 1996 to 2014) and express their opinions about the motives that determined their activity.

Results

Environmental variables recorded in 1996 and 2014 are shown in Figure 2. Information about sedimentary environmental conditions during the sampling of 1996 were derived from Smith et al. (2000). The comparison of the environmental variables indicated significant differences (Table 1). Surface sediment Chl *a* was lower in 2014 than in 1996, while organic carbon was higher in 2014 (Figure 2). The results of the last comparison should be interpreted with caution due to the different methods used for the determination of sedimentary organic matter in 1996 and 2014.

Species richness, total abundance, and BQI-family, all showed an increase during the study period (Figure 3). The three-way ANOVA indicated that there was no interaction effect ($p > 0.05$) between year, season, and treatment on the three dependent variables tested (Table 1). In both species richness and BQI-family, there was a statistically significant interaction between year and treatment ($p < 0.05$). As a result, while there was a significant difference in species richness in and out of trawling zone in 1996 (comparison for factor treatment within the factor 1996, Tukey test; $q = 8.13$, $p < 0.001$), differences were not statistically significant in 2014 (comparison for factor treatment within the factor 2014, Tukey test; $q = 2.687$, $p > 0.05$) indicating that the effect of trawling in 2014 was not as strong as in 1996. Regarding total abundance, the differences in the mean values among the different levels of year and the different levels of treatment are both greater than would be expected by chance ($p < 0.05$). On the

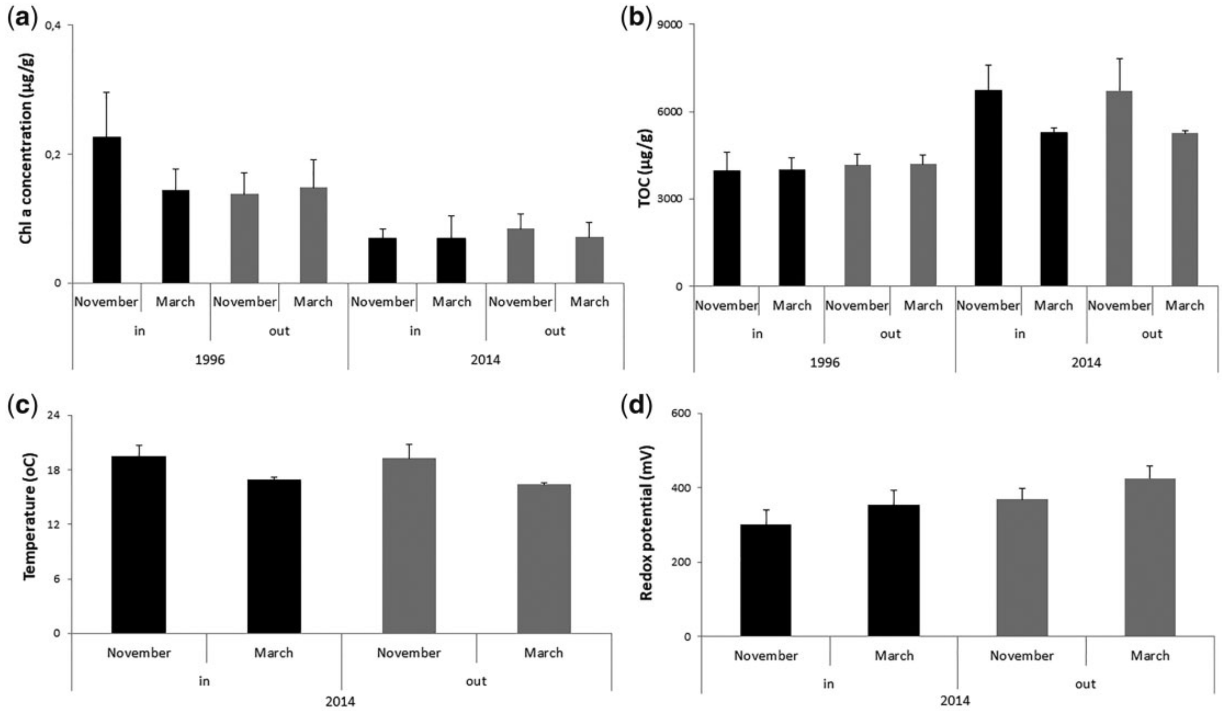

Figure 2. Benthic environmental variables in the study area. Chl *a* (a) and TOC (b) concentrations recorded in both 1996 and 2014 while temperature (c) and redox potential (d) were measured only in 2014. Black columns indicate the stations in the trawled area and grey columns the stations in the adjacent reference area. Error bars indicate standard deviation.

Table 1. Three-way ANOVA of Chl *a*, TOC, species richness, total abundance and BQI-family scores.

		Chl *a*		TOC		Species richness		Total abundance		BQI-family	
Source of variation	**Df**	***F***	***p***	***F***	***p***	***F***	***p***	***F***	***p***	***F***	***p***
Year × season × treatment	1	5.773	**0.020**	0.000	1.000	3.856	0.053	2.037	0.158	3.148	0.08
Season × treatment	1	3.197	0.079	0.002	0.958	0.0961	0.757	1.363	0.247	0.227	0.635
Year × treatment	1	5.248	**0.026**	0.336	0.565	7.407	**0.008**	0.502	0.481	4.11	**0.046**
Year × season	1	1.842	0.180	18.566	**<0.001**	1.805	0.183	0.0726	0.788	0.289	0.592
Year	1	67.835	**<0.001**	122.034	**<0.001**	7.407	**0.008**	14.764	**<0.001**	24.743	**<0.001**
Season	1	3.679	0.060	16.774	**<0.001**	1.625	0.207	0.899	0.346	0.423	0.518
Treatment	1	2.445	0.124	0.210	0.649	29.255	**<0.001**	26.008	**<0.001**	32.334	**<0.001**

Bold types indicate statistically significant differences.

other hand, there was no statistically significant difference ($p > 0.05$) among the levels of season. In all cases, the increases within the fishing lane were higher than in those outside the fishing lane (Table 2).

Trawling activity recorded in the study area during the period 2009–2014 is shown in Figure 4a. In addition, both bottom trawl landings and number of trawlers in the region of Crete showed a decreasing trend from 1996 to 2014 (Figure 4b). The local fishers attributed this trend primarily to economic factors, such as fuel prices, increase in taxes and consumers' preferences for cheaper fish species. On the other hand, they did not consider that overexploitation and legislation changes significantly affected their activity.

Discussion

The comparison of benthic community metrics between the two sampling campaigns with 18 years difference, with seasonal and replicated sampling within this traditional fishing ground and the adjacent untrawled area indicated an increase in macrofaunal abundance and species richness and an improvement in the ecological status in the samples taken recently.

Factors that could potentially induce long-term changes in benthic communities could be either large-scale factors or local factors. Large-scale climatic changes could cause long-term oscillations in abundance and distribution in benthic species (Kröncke *et al.*, 2011; Bonifácio *et al.*, 2018). Even though such factors could affect the benthic communities structure in the study site, it was considered that all stations will be affected in a similar pattern through a change in pelagic primary production and the consequent change in sedimentation of organic material on the seabed (Danovaro *et al.*, 2001; Clare *et al.*, 2017). Instead, the low values of sediment Chl *a* and organic matter concentration both in 1996 and 2014 indicated similar conditions and a rather oligotrophic environment (Hyland *et al.*, 2005; Dimitriou

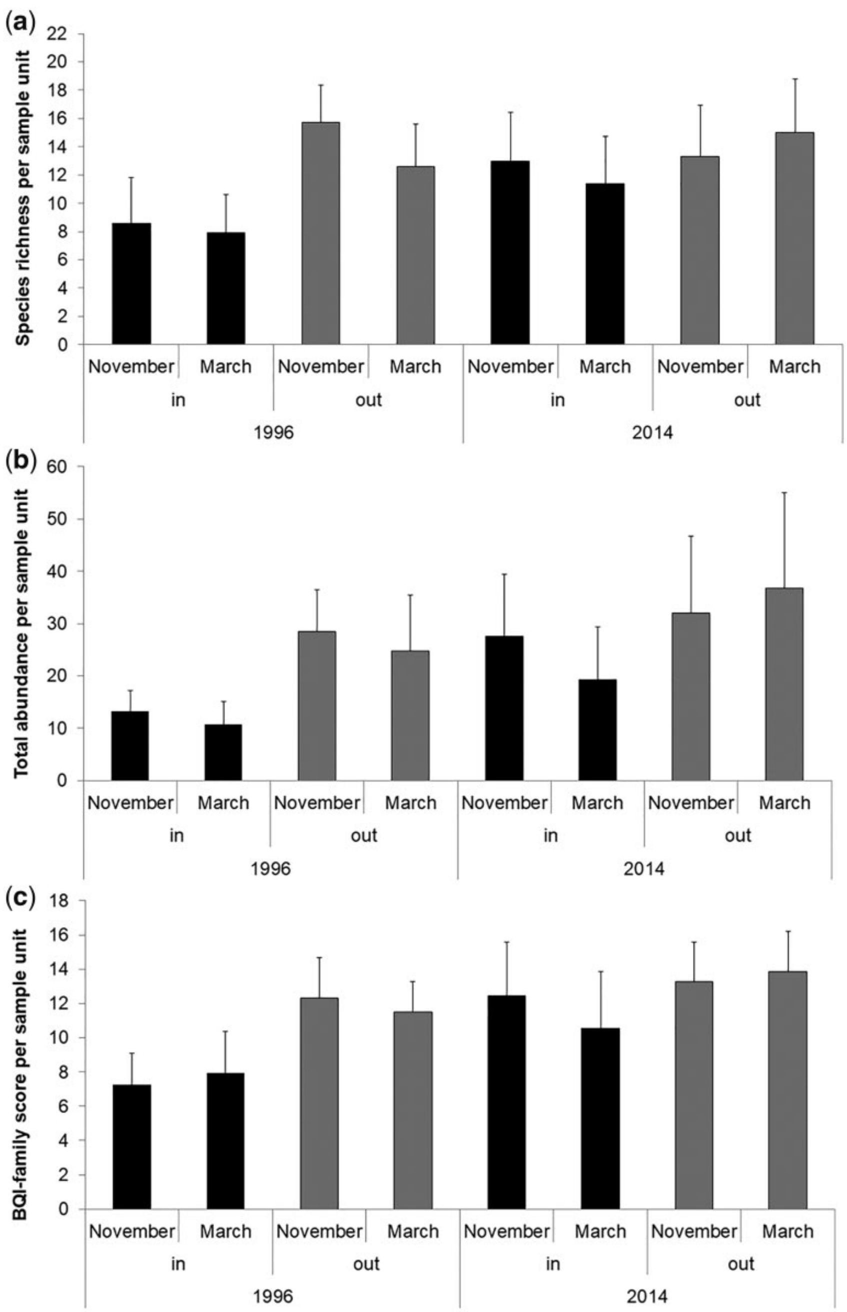

Figure 3. (a) Average number of species, (b) total abundance, and (c) BQI-family score per sampling unit between 1996 and 2014 in the trawled area (black bars) and in the adjacent reference area (grey bars). Error bars indicate standard deviation.

Table 2. Multiple pairwise comparisons for factor year within the levels of factor treatment.

	Species richness		Total abundance		BQI-family	
Comparisons for factor year	***q***	***p***	***q***	***p***	***q***	***p***
Within the trawled area	5.443	**<0.001**	4.551	**0.002**	7.001	**<0.001**
Outside the trawled area	0.000	1	3.134	0.03	2.947	0.041

Bold types indicate statistically significant differences.

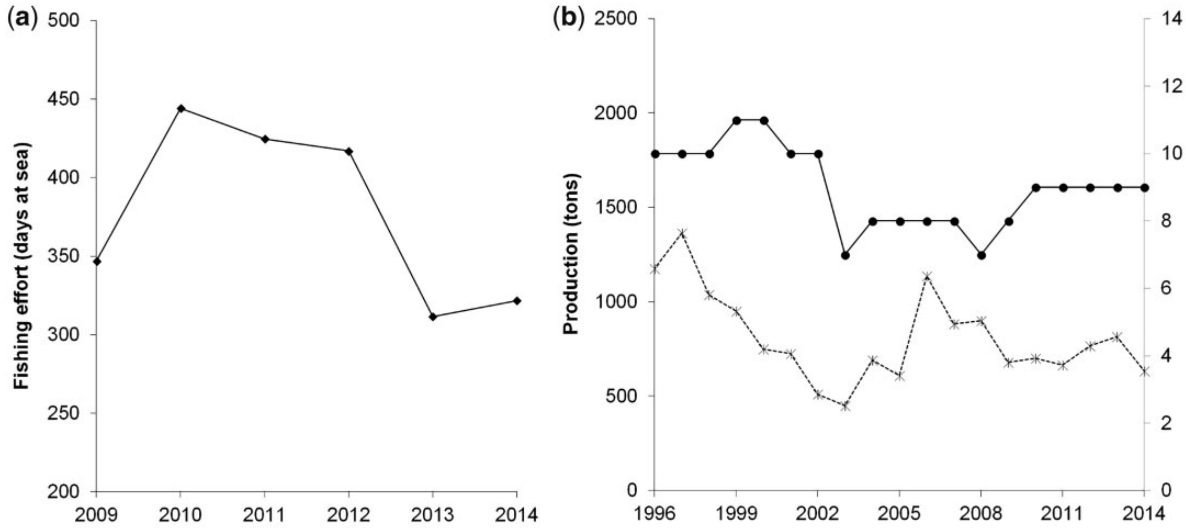

Figure 4. Trawling activity in Heraklion bay during the period 1996–2014 (National Fisheries Data Collection Programme (EPSAD), 2017). (a) Fishing effort in days at sea for trawls as recorded by VMS and (b) fish production (asterisks) in tons for trawls and number of trawling vessels (black circles).

et al., 2017). It was also evident that the increase in diversity metrics in 2014 was not due to thriving of opportunistic/tolerant species but mainly to K-selection species as it may be inferred from the changes in the BQI-family scores.

On the other hand, the most significant differences between years were recorded within the trawling lane. This led us to the conclusion that probably there was a change in trawling activity in Heraklion bay, since the area is considered unaffected by other human impacts. The three variables tested, and specifically the density of benthic species (total abundance per sample), are good indicators of the impacts of increased bottom trawling intensity (Gislason *et al.*, 2017). Changes in the number of individuals recorded could be attributed to increased mortality caused by bottom trawling. As a result, the increase in species density, individual abundance, and ecological status are all signs of a decrease in trawling effort during this period which probably resulted in recovery of the benthic community. Indeed, signs of decline in fishing activity have been detected during the 1996–2014 period in the sampling area.

While the restoration of the benthic community in the stations located inside the trawling lane can be explained by the decline of fishing pressure, the improvement of the benthic metrics in the reference sites is possibly an aftereffect of this restoration. As marine-protected areas (MPAs) can enhance a significant juvenile recruitment to both the protected and adjacent area (Planes *et al.*, 2000; Russ *et al.*, 2004; Harrison *et al.*, 2012), in a similar way the recovery of benthic communities from the physical disturbance caused by bottom trawling probably improved the ecological status and biodiversity in the adjacent areas. Similarly, the decrease in fishing pressure in the traditional fishing zone improved the ecological status in the reference area.

In order to clarify the reasons for the decrease in trawling activity, personal interviews with local fishers were conducted. Interestingly, economic factors were mentioned. Product prices and consumers' income are important drivers for seafood purchasing (Carlucci *et al.*, 2015; Eumofa, 2017). During the economic crisis in Greece, the decrease in gross domestic product (GDP) per capita (Menegaki and Tsagarakis, 2015; Hellenic Statistical Authority, 2016) have resulted in a decrease in per capita consumption and a shift toward cheaper sources of food (Carlucci *et al.*, 2015; Eumofa, 2017). Among all EU countries, the highest decrease in per capita fish consumption was recorded in Greece (−4.5%) and linked to the financial crisis the country has undergone (Eumofa, 2017). In contrast, northern EU countries (Sweden, Denmark, and Finland) increased their per capita consumption by 0.14%. This shrinkage in the demand for fresh fish in the local markets probably became a driver toward the decline in trawling activity. The economic crisis started in 2008 in Greece but its impacts lasting still, also caused a shift in fuel prices. Local fishermen verified that despite the decreased demand for fresh fish, changes in the taxation of fuels resulted in difficulties for them to comply with necessary tax prepayment and preferred to reduce their activity or to fish in shallower areas in order to save fuel. The decrease in the consumption of petroleum products was recorded not only in the fishing industry but also in every sector of the Greek economy during the economic crisis (Roinioti and Koroneos, 2017).

In combination with economic factors, other factors that should be considered were fisheries legislation changes and overexploitation (Stergiou *et al.*, 2007; Moutopoulos and Stergiou, 2012) but according to fishers opinions their influence on trawling activity in the study area during the period 1996–2014 was less significant. Nevertheless, changes in the minimum legal landing sizes, mesh size regulations, minimum distance from the coast where fishing with bottom trawling is allowed, and the permission for foreign fishing vessels to operate for commercial purposes in international waters could be motives for fishermen to search for alternative fishing grounds (Maina *et al.*, 2016).

In the Eastern Mediterranean, Greek fisheries comprise 14.7% of production and support the largest fishing fleet among the EU countries in terms of number of vessels (Eurostat, 2016), the vast majority being small coastal vessels. Additionally, the Greek economy has been facing financial problems since 2008 with obvious impacts on many production sectors (Menegaki and Tsagarakis, 2015), including fisheries. Taking into account the strong relationship between reduced economic activity and environmental pressure (Roinioti and Koroneos, 2017), it could be concluded that at local scales the economic crisis offered at least short-term environmental benefits to the marine ecosystem of the study area as it resulted in a decrease in many sectors of economic activity (Lekakis and Kousis, 2013; Roinioti and Koroneos, 2017). Nevertheless, the large number of small-size enterprises or personal companies and artisanal or semi-industrial vessels, as well as data misreporting and tax compliance set the Greek fisheries and the wider economy apart from other European countries (Machias *et al.,* 2016). Consequently, these short-term environmental benefits recorded in the study area might not be observed in other fishing grounds or might be turned to long-term negative effects on the ecosystem (e.g. overfishing) after a prolonged crisis, originating from violations of the current legislation (e.g. illegal catches) or data misreporting (Tsikliras *et al.,* 2013). In such cases, long-term ecological studies could be beneficial for an ecosystem approach to management. The policy makers should pay the proper attention in order to avoid a possible ecosystem crisis, the consequences of which are difficult to reverse due to ecosystem complexity (Lekakis and Kousis, 2013; Tsikliras *et al.,* 2013).

Data from the present study have shown that a modest decrease in fishing pressure can induce a measurable change in benthic ecological status metrics. There is also an indication that these changes in ecological status had a slight but measurable positive effect on the adjacent control sites as well, probably related to recruitment processes of benthic invertebrates. Nevertheless, our study has not involved comparison of fish populations and abundance between the two sampling periods which could also explain changes in benthic communities as a result of variability in predatory pressure and this is a limitation of our study that should be considered in future research.

In conclusion, our results showed that benthic conditions improved in the fishing lane in comparison to the situation 18 years before. This change may be attributed to a change in fishing effort due to a combination of socioeconomic and policy factors, partly enforced by the prolonged economic crisis in Greece. Hence, once again confirming the strong relationship between economic activities and ecosystem sustainability (Rees, 2003).

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Additional information

The authors declare no competing interests, or other interests that might be perceived to influence the results and/or discussion reported in this article. Correspondence and requests for materials should be addressed to I.T. (grad578@edu.biology.uoc.gr).

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