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PRIMARY RESEARCH PAPER

Premium small scale: the trap fishery for *Plesionika narval* (Decapoda, Pandalidae) in the eastern Mediterranean Sea

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Abstract Small-scale fisheries (SSFs) constitute a substantial component of European fisheries and have a high socioeconomic importance, especially for remote insular areas. Traps produce catches of high quality and value, associated with limited bycatch and low habitat impact. Long-standing trap SSFs in both the Mediterranean and the Atlantic showcase the potential of such SSFs to support remote fishing communities; however, trap SSFs remain relatively understudied. Here, we investigate the spatial and temporal dynamics of a Greek trap SSF targeting *Plesionika narval* (Fabricius, 1787) in the eastern Mediterranean, by means of Generalized Additive Models fitted on fishers' logbook data from 2005 to 2014. The dynamics of both catch per unit effort (CPUE) and profits suggest a pronounced seasonality for this fishery, while there are also signs of local overexploitation in the traditional fishing grounds. Additionally, small vessels (< 12 m) report higher CPUEs than larger vessels. Our results point to management measures that could improve the sustainability of this valuable SSF, such as changes in the spatial and temporal allocation of fishing effort, and in fleet composition. The insights gained from this study are relevant to other localized trap SSFs and illustrate

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the socioeconomic potential of such fisheries for remote fishing communities.

Keywords Dodecanese · Generalized additive models · Logbook data · Narwal shrimp · Small-scale fisheries

Introduction

Demersal crustaceans are among the most valuable species for Mediterranean fisheries (STECF, 2017a). Some of them, such as Norway lobster, *Nephrops norvegicus* (Linnaeus, 1758), spot-tail mantis shrimp, *Squilla mantis* (Linnaeus, 1758), blue and red shrimp *Aristeus antennatus* (Risso, 1816), giant red shrimp *Aristaeomorpha foliacea* (Risso, 1827) and deep-water rose shrimp *Parapenaeus longirostris* (Lucas, 1846) are heavily exploited by towed gears throughout the Mediterranean Sea, often above sustainable levels (Vasilakopoulos & Maravelias, 2016). Stocks of these important crustacean species are analytically assessed and relevant management advice is produced by dedicated expert working groups (e.g. STECF, 2016, 2017b). However, there are also other valuable crustacean species in the Mediterranean supporting localized small-scale fisheries (SSFs) that remain understudied. Such SSFs are often of great socioeconomic importance to local communities, especially in small islands and remote coastal areas. The Common Fisheries Policy (CFP) in Europe has called for actions to ensure the sustainability of such local fisheries resources and their associated SSFs, so as to enable the communities depending on them to survive and prosper (European Union, 2013; Malta MedFish4Ever Ministerial Declaration, 2017). However, fisheries research tends to overlook locally important SSFs, leading to information deficits and poor decision-making (Oliveira Júnior et al., 2016).

The trap fisheries for Pandalid shrimps (Decapoda, Pandalidae) in the Mediterranean Sea are good examples of locally important SSFs that promote the prosperity of remote fishing communities. *Plesionika narval* (Fabricius, 1787) and other sympatric Pandalid species form localized aggregations that support SSFs in Greece (southeastern Aegean Sea; Thessalou-Legaki et al., 1989; Kalogirou et al., 2017), Italy (south Tyrrhenian Sea; Colloca, 2002; Castriota et al., 2004) and the Spanish Mediterranean shelf (Garcia-Rodriguez et al., 2000). Similar SSFs for Pandalid shrimps also operate in some eastern Atlantic islands, such as the Canary Islands (Gonzalez et al., 1997, 2001; Arrasate-Lopez et al., 2012), Madeira (Sousa et al., 2014) and the Azores (Martins & Hargreaves, 1991). The Greek SSF targeting *P. narval* operates in the Dodecanese archipelago (southeastern Aegean Sea) (Fig. 1). This remote insular area is highly dependent on fisheries (Tzanatos et al., 2005). The SSF for *P. narval* in the Dodecanese is thought to be one of the most profitable SSFs in Greece, and constitutes a traditional fishing activity with high socioeconomic importance, especially for the smaller islands of the archipelago (Kalogirou et al., 2017). The traditional fishing grounds for *P. narval* extend around the central Dodecanese islands of Symi, Chalki and Rhodes (Fig. 1). This is reflected to the Greek common name of the species ('Symi shrimp'). In recent years, the SSF for *P. narval* in the Dodecanese has been expanding into new areas ranging from Kastellorizo in the east to Astypalaea in the west and from Kasos and Crete in the south to Kalymnos in the north (Fig. 1).

The trap fishery for *P. narval* in the Dodecanese is carried out by fishing vessels ranging from 4 to 15 m in length, with the vast majority of them being smaller than 12 m, i.e. small-scale vessels (European Union, 2014). The fleet is primarily active from April to September. Square or round shrimp traps with a mesh size of 8 to 12 mm are used. The bait used is dough made of flour, water and fermented fish. The traps are usually deployed from dusk till dawn, mainly over rocky substrates, at depths ranging from 5 to 200 m. The shrimps caught are washed and headed on board, and they are subsequently sold to restaurants or fishmongers. *P. narval* shrimps fetch high prices (around 25 €/kg), with demand being particularly high during the summer months, when the tourist season peaks in the Dodecanese. However, the seasonal and annual fluctuations of the *P. narval* stock, the high cost of the shrimp traps and legislative constraints limit the entry of more fishers to this fishery.

To promote the sustainable exploitation of the valuable but understudied *P. narval* stock in the Dodecanese, detailed studies of both the stock and the SSF are needed. Here, we analyse the dynamics of the SSF in 2005–2014 using fisheries-dependent data, in order to elucidate the role of temporal and spatial

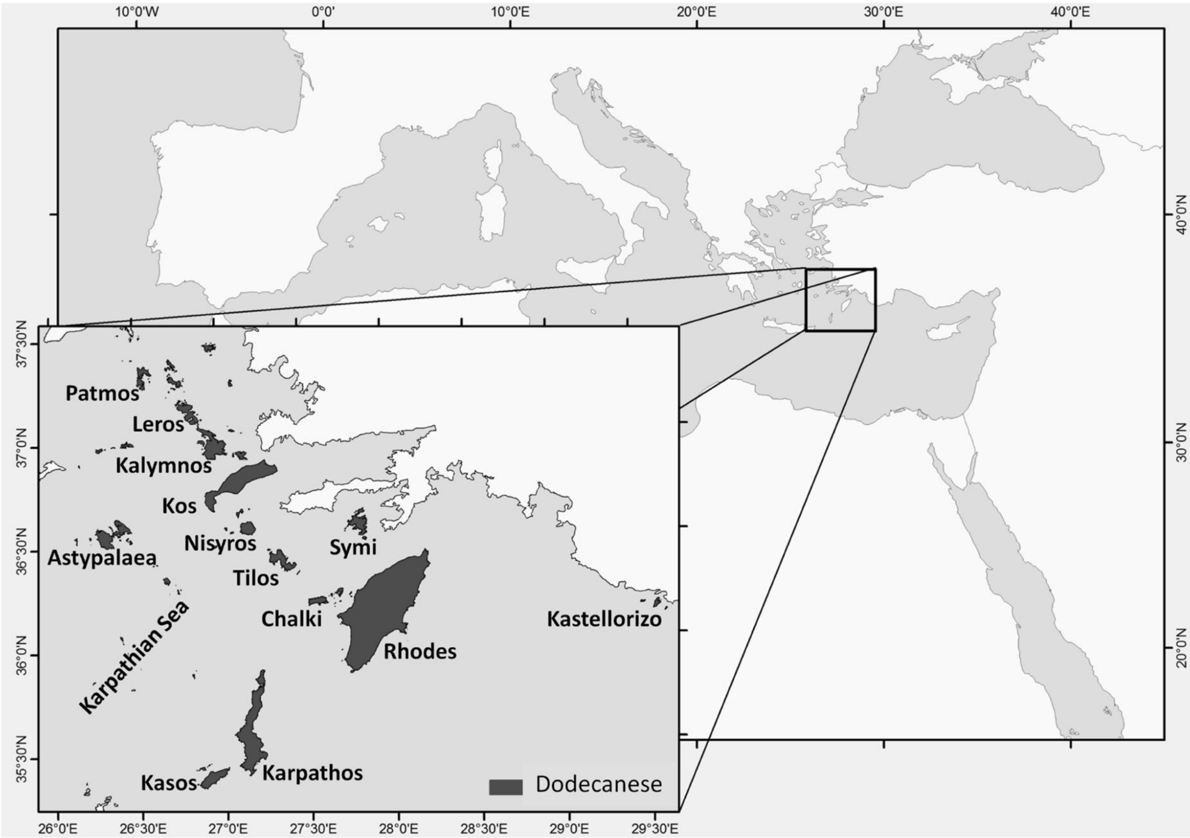

Fig. 1 The Dodecanese archipelago in the eastern Mediterranean Sea, where the studied SSF for *P. narval* operates

variables, as well as of vessel size. Catch per unit effort (CPUE) data were retrieved from fishers' logbooks, while economic data were collected using relevant questionnaires. The effects of year, day of year, vessel size and fishing area on both CPUE and profits were analysed by fitting suitable Generalized Additive Models (GAMs) (Hastie & Tibshirani, 1990; Maravelias & Reid, 1997; Maravelias, 1997, 1999). This study extends our understanding of this valuable SSF, and has important implications for its management, in terms of optimizing the spatio-temporal allocation of effort and fleet structure. The lessons learned here are transferable to other localized trap SSFs in the Mediterranean and elsewhere.

Materials and methods

Data collection

From 2005 onwards, a closed period for trap fisheries in Greek waters has been in place from 01/05 to 31/07. During 2005–2014, ca. 40 fishing permits were being issued annually by the Department for Fisheries of the Prefecture of the Southern Aegean (DoF) to allow trap fishing for *P. narval* during the closed period, with an upper limit of 150 traps per fishing vessel. These permits came with the obligation for the fishers to submit logbook data providing details of their fishing activity for their every fishing day. These logbook data ('logbook dataset' hereafter) were made available from the Department for Fisheries of the Prefecture of the Southern Aegean (DoF) for this study. The logbook dataset included, among others, vessel and owner name, length overall and horse power of the fishing vessel, name of the fishing area, time of day when the traps were set and retrieved, headed weight

('weight' hereafter) of shrimps caught, and number of traps that had been deployed. From all fishing vessels with a permit to operate during the closed period (01/05–31/07) in 2005–2014, only 13 vessels submitted consistent data (i.e. logbook data sheets including all the required information) that were utilized in this study. In total, data for 854 days at sea were available for the period 2005–2014 from vessels ranging from 5 to 15 m in length (Supplementary Table 1). No data were available for the years 2007 and 2008, due to problems in the logbook collection by the responsible authority.

Besides the logbook dataset, economic data were collected in 2015 from 21 fishing vessels, ranging in length from 4 to 15 m, using suitable questionnaires ('economic dataset' hereafter). Through these questionnaires, trap fishers targeting *P. narval* provided information on both the total fixed and total variable costs of their fishing operations during the previous year (2014), the average selling price and their total fishing days. These economic data (Supplementary Table 2) were used to infer the economic dynamics of the fishery in 2005–2014.

Data organization

CPUE estimates were extracted from the logbook dataset for each fishing day by dividing the weight of *P. narval* caught by the number of traps deployed. This way, variable *CPUE* was constructed expressing the mean weight in kg of *P. narval* caught per trap and fishing day. Fishing areas (variable *Area*) were grouped according to the nearest large island (with the exception of the islets of the Karpathian Sea that were grouped together) into ten categories (Fig. 1): Astypalaea, Chalki, Karpathos, Karpathian Sea islets, Kasos, Kos, Nisyros, Rhodes, Symi and Tilos. Fishing vessels were grouped into two categories according to their length (variable *Lengthclass*): 'small' (5–12 m; 10 vessels) and 'large' (12.1–15 m; three vessels). This division was based on the fact that small vessels are usually operated by a single or two fishers and perform shorter fishing trips (from a single day up to a week), while large vessels are typically operated by three fishers and carry out longer fishing trips (up to 2 weeks). The day of year that each fishing day occurred (variable *Day*) was quantified continuously over a 1–365 scale, where day 1 is the 1st of January and day 365 is the 31st of December. Variable *Year* was quantified as a factor with eight levels and included all years between 2005 and 2014, except 2007 and 2008 when there were no data available.

A mean value of expenses per fishing day was calculated for each of the 21 vessels of the economic dataset, and the relationship between these expenses (E) and vessel length (VL) was investigated. Expenses did not include an imputed value for unpaid labour (STECF, 2017a). Vessel length was considered to be a good predictor of expenses per fishing day, given that the bulk of the fishing expenses come from fuel consumption and boat/trap maintenance that are related to the size of the boat (Supplementary Table 3). Using the relationship between expenses and vessel length calculated from the economic dataset, fixed expenses per fishing day were assigned to each of the 13 vessels in the logbook dataset for 2005–2014. Income per fishing day was then calculated by multiplying the weight of *P. narval* caught by the questionnaire-derived average selling price (25 €/kg) that was largely unchanged in 2005–2014. Profits per fishing day (variable *Profit*) were calculated by subtracting the expenses per fishing day from the respective income.

A sensitivity analysis was also carried out, whereby expenses and *Profit* for every year were recalculated to account for the difference in the fuel price of every year in relation to 2014.

Statistical analysis

The dependence of *CPUE* and *Profit* on the four explanatory variables *Year*, *Area*, *Lengthclass* and *Day* was investigated using GAMs (Hastie & Tibshirani, 1990; Maravelias, 1997; 1999). GAMs were chosen because they are suitable to analyse nonlinear relationships between a response variable and multiple explanatory variables and they are less restrictive in assumptions regarding the underlying distribution of data than the multiple regression (Hastie & Tibshirani, 1990). Prior to the analysis, pairwise correlations between the explanatory variables were investigated to ensure an adequate representation of all different combinations of explanatory variables in the dataset and avoid collinearities, and the shape of the distributions of the continuous variables was examined. To ensure normal distributions of the response variables, log and square root transformations were applied to *CPUE* and *Profit*, respectively. A value of 25 was added to all *Profit* estimates prior to the square root transformation to ensure positive values. Residual plots were used to identify the most appropriate link functions in the GAMs. For both *CPUE* and *Profit*, two Gaussian models with identity link functions were found to provide adequate fits. The models were fitted using stepwise forward selection, and the Akaike Information Criterion (AIC) was used to detect the relative importance of each explanatory variable and determine the order of the explanatory variables that should be included in the final model (Tserpes et al., 2008; Vasilakopoulos et al., 2016). Stepwise forward variable entry continued until additional variables no longer resulted to reductions in the AIC larger than two units (Burnham & Anderson, 2002). The cumulative percentage of the total deviance explained by adding each variable within the stepwise model selection process was also calculated (Tserpes et al., 2008; Vasilakopoulos et al., 2016). The analysis was carried out using of the 'mgcv' package of R statistical software version 3.4.2.

Results

A linear model of Expenses (*E*) ~ Vessel Length (*VL*) was fitted using the data of the economic dataset (Supplementary Fig. 1)

$$Expenses\,(E) = 6.04 \text{ Vessel Length } (VL) + 16.93. \quad (1)$$

This linear model (1) provided a better fit than the null model, with AICs being 207.9 and 211.5, respectively. Additionally, the steepness coefficient of (1) was statistically significant at the 0.05 level ($t = 2.393$, $P = 0.027$) and the residual plots were acceptable (Supplementary Fig. 2). Model (1) was then used to estimate the expenses per day of each vessel, and subsequently *Profit*, in the logbook dataset.

CPUE values ranged, prior to the log transformation, from 0.02 to 0.60 kg/trap, with a median value of 0.14 kg/trap. *Profit* values ranged, prior to the square root transformation, from − 24 to 1601 €, with a median value of 417 €. Forward stepwise addition of variables to the GAM for *CPUE* suggested that all four independent variables examined were included in the optimal model (lowest AIC value), which explained 47.2% of the variability in *CPUE* (Table 1). Similarly, the stepwise addition of variables in the GAM for *Profit* suggested that all four variables were retained in the optimal model and explained 51.6% of the variability in *Profit* (Table 1). The main difference between the optimal models for *CPUE* and *Profit* was that *Day* ranked higher than all other variables, followed by *Area* and *Year*, in the *CPUE* model, while *Area* and *Year* ranked higher than *Day* in the *Profit* model. Examination of the residual distribution of the final GAMs for both *CPUE* (Supplementary Fig. 3) and *Profit* (Supplementary Fig. 4) suggested a good fit in both cases.

The effects of the four explanatory variables on *CPUE* and *Profit* were similar in the case of *Day*, *Area* and *Year*, but differed in the case of *Lengthclass*. A strong seasonality was revealed by the shape of the effect of *Day* on both response variables (Fig. 2). Both *CPUE* and *Profit* were increasing rapidly from March to April, reaching their highest values in May. This increasing trend was followed by a decline from June to October. May was the most productive and profitable month for the SSF. The increasing and decreasing trends in the months before and after May, respectively, were steeper for *CPUE* (Fig. 2a) than *Profit* (Fig. 2b).

Regarding fishing areas, Chalki was found to be the least productive and profitable area, followed by Symi (Fig. 3). By contrast, Astypalaea, Kos, Kasos and Nisyros exhibited higher *CPUE* and *Profit* than the other areas. In other words, areas within the traditional and most exploited fishing grounds in Symi and Chalki and also in nearby Rhodes and Tilos, were less productive and profitable than areas further away from the core of the fishing operations (Fig. 1).

In the case of *Year*, no consistent increasing or decreasing trends were observed in the effects on *CPUE* and *Profit* during 2005–2014, apart from somewhat lower CPUE values after 2005 (Fig. 4). Years 2005 and 2010 were associated with the highest and lowest values of *CPUE*, respectively (Fig. 4a), while the highest and lowest values of *Profit* were observed in years 2009 and 2006, respectively (Fig. 4b).

An intriguing discrepancy emerged from the investigation of the effect of *Lengthclass* on *CPUE* and *Profit* (Fig. 5). Small vessels exhibited higher *CPUE* than large vessels (Fig. 5a); however, their *Profit* was unsurprisingly smaller (Fig. 5b). This discrepancy

Table 1 ANOVA table of the optimal GAMs for *CPUE* and *Profit* of the SSF targeting *P. narval* in the Dodecanese. Variables are ranked in descending order of importance as indicated from the stepwise model selection process based on the reduction of the AIC value

Variable	Residual d.f.	Residual deviance	AIC	*P* value	Cumulative deviance explained (%)
CPUE GAM					
Mean	853	256	1400		
Day	850	219	1273	< 0.001	14.4
Area	841	186	1150	< 0.001	27.4
Year	834	147	965	< 0.001	42.5
Lengthclass	833	135	895	< 0.001	47.2
Profit GAM					
Mean	853	38245	5674		
Area	844	29835	5480	< 0.001	22.0
Year	837	23185	5279	< 0.001	39.4
Day	833	18629	5099	< 0.001	51.3
Lengthclass	832	18493	5095	0.012	51.6

suggested operating differences between vessels of different sizes.

Recalculating expenses and *Profit* to account for changes in fuel price over the studied period had negligible effect on the results, owing to the fact that fuel accounts for about half of the total expenses (Supplementary Table 3), and the income being relatively high compared to expenses.

Discussion

This study of the SSF for *P. narval* in the Dodecanese provides new insights on the dynamics and fishing ecology of an important fishery resource. Notably, while there are distinct fluctuations in CPUE related to seasonal and spatial variability, the profits of the fishing fleet estimated here are very high compared to other Greek SSFs, as reported by AGRERI (2017) and STECF (2017a). This highlights the importance of the fishery for the local communities and the associated need to manage it in a sustainable way. Our findings on the dependence of CPUE and profits on seasonal, spatial and technical parameters can be used to improve the management of this valuable fishery. The insights gained are also relevant to other similar trap fisheries with high local importance in the Mediterranean and beyond, if tailored to the specific characteristics of these other fisheries through dedicated case studies (Garcia-Rodriguez et al., 2000; Gonzalez et al., 2001; Colloca, 2002; Castriota et al., 2004; Arrasate-Lopez et al., 2012; Sousa et al., 2014).

Our analysis did not indicate any long-term unidirectional trends in the CPUE and profits of the studied SSF after 2005; hence, there is no indication of a general increase or decrease of the resource in recent years. However, strong seasonal fluctuations were revealed: both CPUE and profits peak in May, a period that corresponds to the beginning of the tourist season in the Dodecanese that is associated with a high market demand for *P. narval*. May also corresponds to the beginning of the main reproduction period of *P. narval* (Anastasopoulou et al., 2017). During that period, *P. narval* specimens move to shallower waters and become more mobile, hence becoming more accessible to fishing gears (Kalogirou et al., 2017). The declining availability of *P. narval* through the summer months is probably due to the fact that catches are largely dominated by specimens that were mainly spawned the year before (age 1 specimens). Therefore, it is speculated that the increasing trend from March to May indicates the increasing availability of *P. narval* to fishing gears, while the decrease from May to October indicates the gradual depletion of the single cohort that dominates the catches. Therefore, shifting the allocation of the SSF's fishing effort towards the summer months could potentially

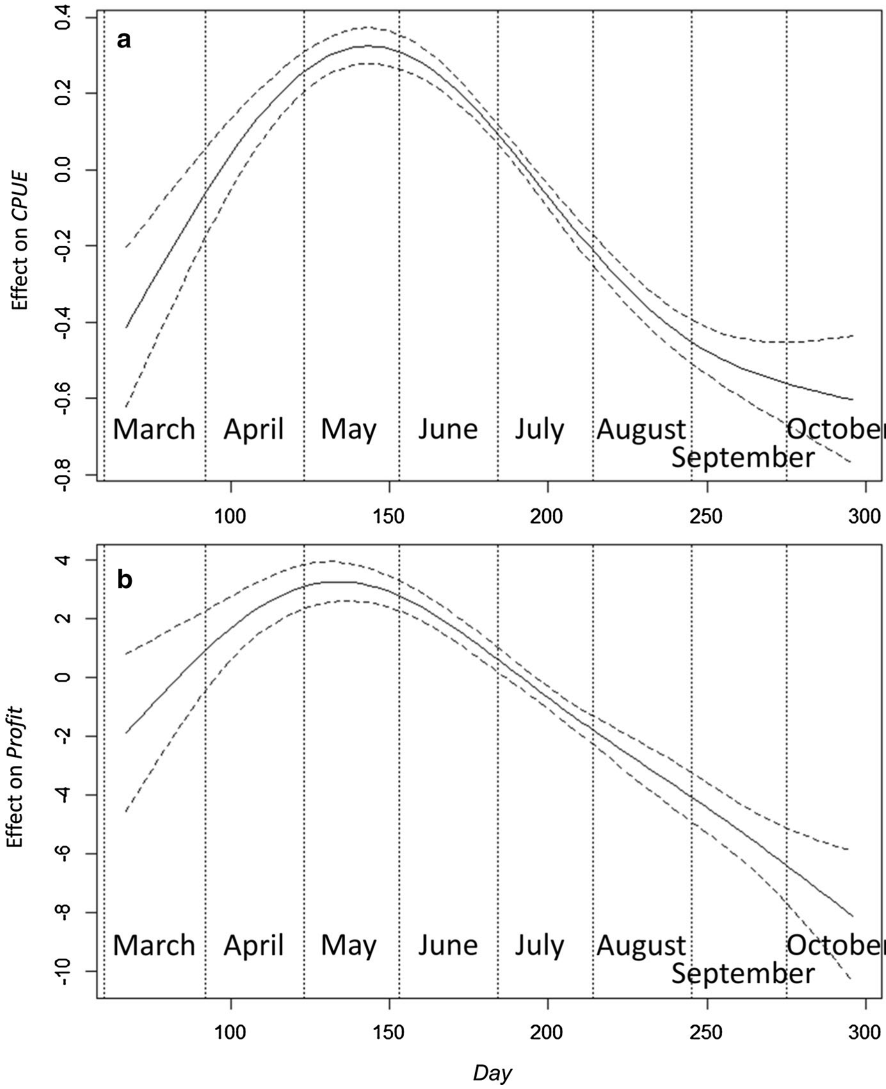

Fig. 2 Partial effects of *Day* on *CPUE* (**a**) and *Profit* (**b**) inferred from the fitted GAMs. Dashed lines indicate the 95% confidence intervals

allow the production of higher catches right when market demand is at its highest. Currently, there is a fishing ban in place from May to July, except for those fishers who have acquired special permits. Opening the fishery throughout the summer (June–August) and closing it for part or all of the remaining year instead would allow the synchronization of high yields with high demand.

Regarding the effect of the fishing area, the analysis suggested that the traditional fishing grounds, primarily of Chalki and Symi and to a lesser extent of Rhodes, Karpathos and Tilos, where the majority of the fishing activity is concentrated, are less productive and profitable than more remote fishing grounds such as in Astypalaea, Kasos, Kos and Nisyros. This discrepancy may be indicative of a local overexploitation of the resource in areas with a long history of intense fishing pressure. On the positive side, it also hints at potential gains from a range expansion of the SSF to areas with higher productivity, away from the traditional fishing grounds. Such an expansion could potentially also include areas that have not been sampled in this study, such as Kalymnos, Kastellorizo and Crete. Hence, a sound management strategy would be to limit the fishing pressure in the traditional fishing grounds that show signs of overexploitation, and encourage a shift of the fishery towards more productive areas. Of course, the SSF in these new

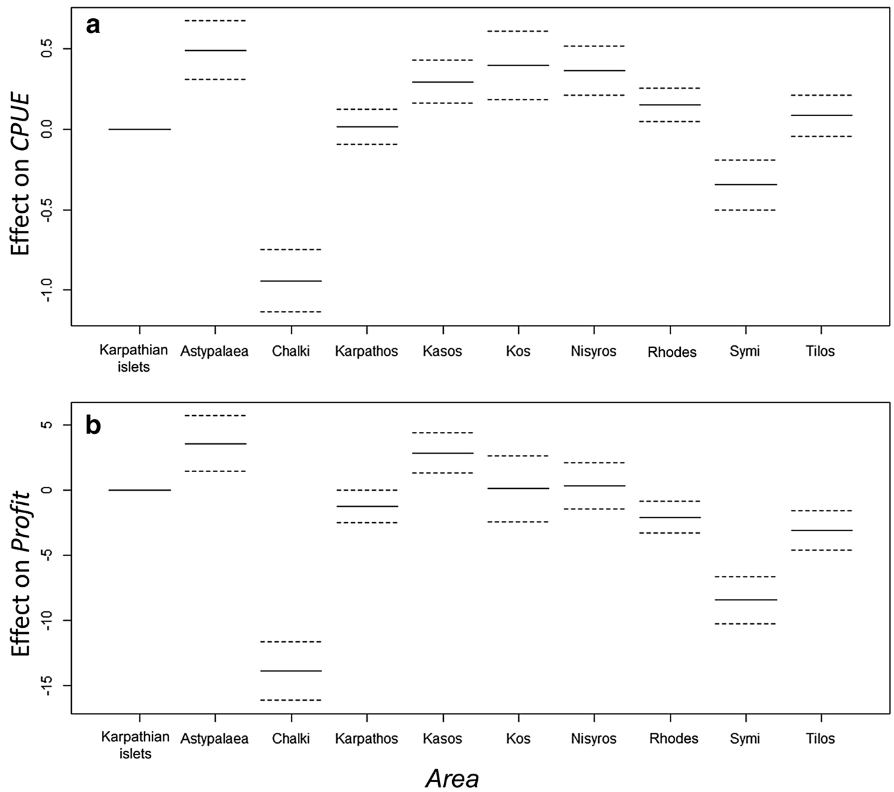

Fig. 3 Partial effects of *Area* on *CPUE* (**a**) and *Profit* (**b**) inferred from the fitted GAMs. Different areas are shown in Fig. 1. Dashed lines indicate the 95% confidence intervals

areas would have to be carefully monitored to avoid overexploitation.

A notable finding of this analysis was the lower CPUE observed in the large vessels compared to the small ones. This could be an empirical manifestation of the economic principle of diminishing marginal productivity (Campbell & Owen, 1994; Zugarramurdi et al., 1995). This principle predicts that as effort (number of traps) increases, a point will be reached where the resulting increases in the catch will start becoming smaller. In the case of the Dodecanese SSF, the exploited *P. narval* stock has a patchy distribution, possibly related to shoaling behaviour, and the deployment of fewer traps from the small vessels means that the area covered is small and carefully selected by the fisher on the basis of its productivity. Meanwhile, larger vessels deploy more traps over wider areas that make it more likely to fish in both productive and unproductive areas. Additionally, fishers in small vessels have been observed to collect meticulously all shrimps caught in their traps, while fishers in larger vessels often do not empty traps with small quantities of shrimps to save operational time. Unsurprisingly, despite their higher CPUE, small vessels exhibit lower daily profits than large vessels due to their lower number of traps and total catch. These patterns suggest that management measures encouraging exploitation by smaller sized vessels with less traps, rather than large vessels with more traps, would improve the efficiency of the fishery. Alternatively, such an improvement could be achieved by reducing the maximum number of traps allowed on each fishing vessel.

It should be noted that the success of management measures identified here as having the potential to increase sustainability of the studied SSF prerequisites correct implementation. Indeed, the track record of fishery management in the Mediterranean in general is not great, owing, among others, to the problematic control and enforcement regimes, coupled with low levels of compliance (Vasilakopoulos et al., 2014; Fernandes et al., 2017). On its own, new research on less studied fisheries will not necessarily bring benefits in terms of sustainability and profitability; it is the social decisions on whether and how to implement that knowledge that will lead to tangible results.

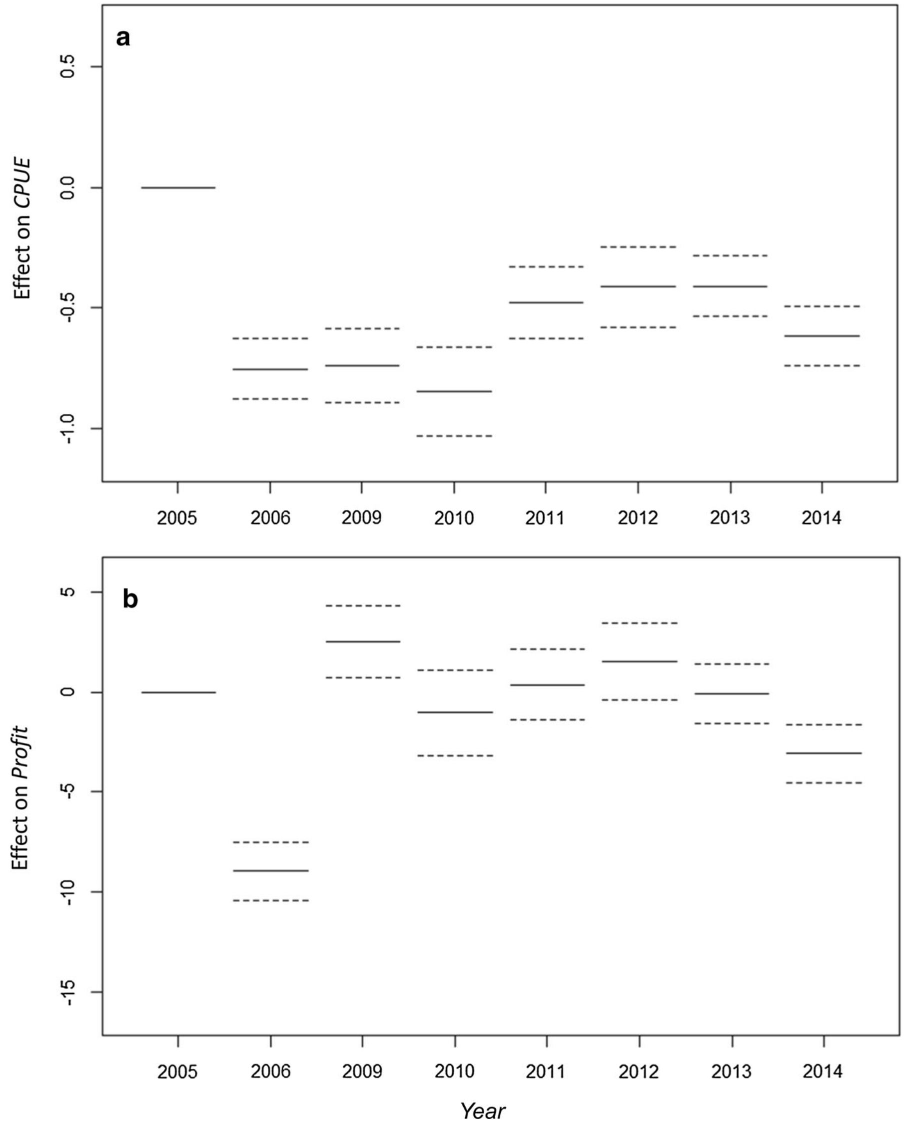

Fig. 4 Partial effects of *Year* on *CPUE* (**a**) and *Profit* (**b**) inferred from the fitted GAMs. Dashed lines indicate the 95% confidence intervals

This study was based on the analysis of a logbook dataset from 13 fishing vessels, i.e. less than a third of the SSF fleet targeting *P. narval* in the Dodecanese throughout the year. Therefore, the results should be interpreted with caution; the analysis of additional data in the future could strengthen and extend the findings of this study. One of the issues with the analysed dataset was that the majority of the data came from the traditional fishing grounds and referred to the period when fishing activity is at its peak (May–August) (Supplementary Table 1). Collecting more data from the autumn and winter months and from the areas further away from the traditional fishing grounds, such as the islands of Kos, Astypalaea, and Kasos, as well as from unsampled islands such as Kalymnos, Kastellorizo and Crete (Fig. 1) would allow a better understanding of both the dynamics of the exploited *P. narval* stock and the potential for expansion of the SSF. Additionally, the reconstruction of the economic dataset for 2005–2014 based on relevant data from 2014 was carried out using a reasonable methodological approach and was found to be robust to the fuel price fluctuations, but it was still far from ideal. In future investigations of this and other SSFs, economic data should be collected for each day at sea. This way it could be clarified, for example, if it

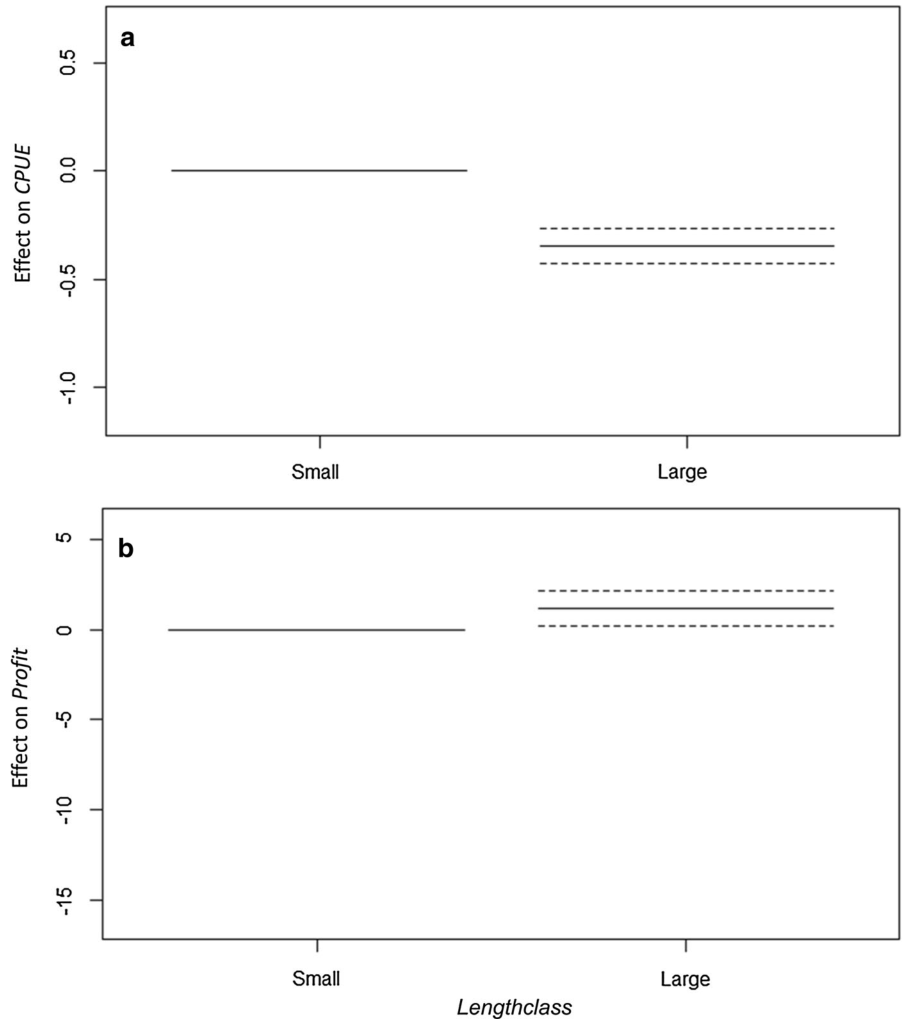

Fig. 5 Partial effects of *Lengthclass* on *CPUE* (**a**) and *Profit* (**b**) inferred from the fitted GAMs. Dashed lines indicate the 95% confidence intervals

would indeed be profitable for vessels to operate in more productive areas that lie further away from their traditional fishing grounds and home ports.

Trap fishing is a fuel efficient and fairly selective fishing activity with minimal habitat impacts and delivers catches of high quality (Suuronen et al., 2012). The preservation and expansion of trap fisheries in the Mediterranean Sea, an area characterized by intense overexploitation of most of its fisheries resources (Vasilakopoulos et al., 2014; Vasilakopoulos & Maravelias, 2016), could help reduce the use of less sustainable fishing gears and practices by the SSFs (e.g. boat/beach seines, trammel nets). This is the case especially for remote coastal or insular communities relying heavily on fishing. Therefore, there is a need for further studies to elucidate the characteristics, dynamics and economic potential of trap SSFs, both in the Mediterranean Sea and in other global marine areas with similar characteristics.

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