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ECOSYSTEMS AND SUSTAINABILITY

Spatial management of the Mediterranean bottom-trawl fisheries: the case of the southern Aegean Sea

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Abstract A time series of survey abundance indices for commercially important demersal fish and cephalopod species, inhabiting the narrow continental shelf of the southern Aegean Sea, is analyzed in relation to the topography of the area in order to evaluate the impact of different spatial fishery bans on the bottom-trawl fishery. With reference to the current situation, results suggested that implementation of the 1967/2006 EC Regulation, which bans bottom-trawl activities within 1.5 NM off the coast, will significantly increase (20–80%, depending on the species) the proportion of the populations that are inaccessible to the bottom-trawl fishery. It might also result in shifting of fishing activities toward deeper waters, adding fishing pressure onto slope resources inhabiting the slope. As depth determines, to a large extent, the distribution pattern of the species, it constitutes a variable of crucial importance for the spatial management of marine fisheries and should be taken into account when adopting relevant management regimes.

Keywords Mediterranean · Demersal fish · Bottom-trawl fisheries · Management · Distribution

Introduction

Management of all Mediterranean stocks, apart from bluefin tuna, is exclusively based on various effort control regimes. Direct regulation of effort is achieved through a licensing system allowing fishing in certain areas and seasons for particular vessels and gears, as well as through restrictions on the fishing capacity of licensed vessels (vessel tonnage and engine power or gear size restrictions). Direct effort regulation is typically accompanied by methods of indirect effort control, including various technical measures and management actions. Examples of such methods are closed areas and seasons, which indirectly restrict fishery input, gear restrictions such as mesh size, and minimum landing size regulations. In fact, indirect methods control the catch that can be achieved for a given effort (Nielsen et al., 2006).

In the case of bottom-trawl fisheries in Mediterranean EU waters effort control management is implemented through national and international regulations, the latter established in the frames of the Common Fisheries Policy (CFP). Apart from capacity restriction rules, i.e., limitation on national fleets horsepower and gross tonnage, the CFP controls effort through a series of technical measures and

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management actions including: (a) prohibition of bottom trawling either within three miles of the coast or in depths less than 50 m (whatever comes first), as well as, on sensitive habitats (e.g. *Posidonia* and maerl beds), (b) a minimum mesh size of 40 mm for bottom-trawls cod-end, and (c) minimum landing sizes for a series of commercial species.

Bottom-trawling limitations in depths less than 50 m aim to protect the most shallow part of the continental shelf, which is an area under the direct influence of many physical processes and also much affected by human activities (Kaiser et al., 2005; Halpern et al., 2008). Due to its high productivity, most of the world fisheries production originates from the continental shelf zone, despite its relatively low global percentage (~8%), with reference to the total marine area (Pauly & Christensen, 1995). In the Mediterranean Sea, the vast majority of the fishing activities are concentrated along the continental shelf, although the extent of this zone on the basin is relatively narrow (Caddy, 1993; Lleonart & Maynou, 2003). This results in serious concerns about overfishing of the shelf-associated resources and destruction of their habitats (Caddy, 1993; Caddy et al., 1998). It is obvious that regulations controlling fishing activities on the continental shelf zone incorporate various elements of the marine environment and have a broader effect than managing single commercial stocks, encompassing the context of the ecosystem approach to fisheries.

A recent EU Regulation (1967/2006) attempts to strengthen the protection of shelf areas, and, apart from banning fishing activities above coralligenous habitats and maerl beds, is calling for an additional measure that includes prohibition of bottom trawling to a distance of 1.5 NM from the coast, independently of depth. It is, however, recognized that this prohibition may be harmful for fisheries operating in areas with a narrow continental shelf, as it would restrict their fishing activities to deeper waters prohibiting access to important fishery resources inhabiting more shallow continental areas; i.e., depths less than 150–200 m. For this reason, the EU countries have been asked to justify local exceptions from the banning measure, based on the amount of resources and income that will be lost if the regulation is applied.

In the case of Greece, bottom trawling within one mile off the coast is already prohibited by national legislation making a large part of the coastal fisheries resources inaccessible to the gear. It is expected that the 1.5 NM ban will significantly restrict bottom-trawl activities, especially in areas with a particularly narrow continental shelf such as the southern part of the Aegean Sea.

In the present study, based on a time series of survey data, we attempt to evaluate the effects on the volume and composition of bottom-trawl catches, resulting from the application of the new EU regulation on the southern Aegean Sea. We focus on a list of commercially important continental shelf species and, based on their depth distribution pattern and the topography of the area, try to evaluate the amount of the resource that is/will be inaccessible to the trawl fishery under different management scenarios.

Materials and methods

The depth distribution pattern of the main target species of the bottom-trawl fishery operating along the continental shelf of the southern Aegean Sea (Fig. 1) was identified through the analysis of a time series of survey abundance indices. The list of species included: *Mullus surmuletus*, *Diplodus annularis*, *Mullus barbatus*, *Eledone moschata*, *Loligo vulgaris*, *Octopus vulgaris*, *Pagellus erythrinus*, *Spicara flexuosa*, *Spicara smaris*, *Sepia officinalis*, and *Boops boops*. These species comprise the main bulk of trawl catches in the examined area (Tsimenides et al., 1991; Tserpes et al., 1999; Tserpes & Peristeraki, 2002) and they are also the main target species for most Mediterranean coastal trawl fisheries (Papaconstantinou & Farrugio, 2000).

Abundance indices were obtained from the "MEDITS" experimental bottom-trawl surveys carried out during the 1996–2006 period in the southern Aegean Sea. The survey covers a large part of the Mediterranean basin mainly aiming to monitor abundance fluctuations of demersal species and includes annual sampling at pre-defined stations, accomplished from late spring to middle summer. Further details on the sampling protocol can be found elsewhere (Bertrand et al., 2000, 2002). Since 1996 (with the exception of 2002, when the survey was not accomplished), the sampling scheme of the Greek "MEDITS" in the southern Aegean Sea covers a total

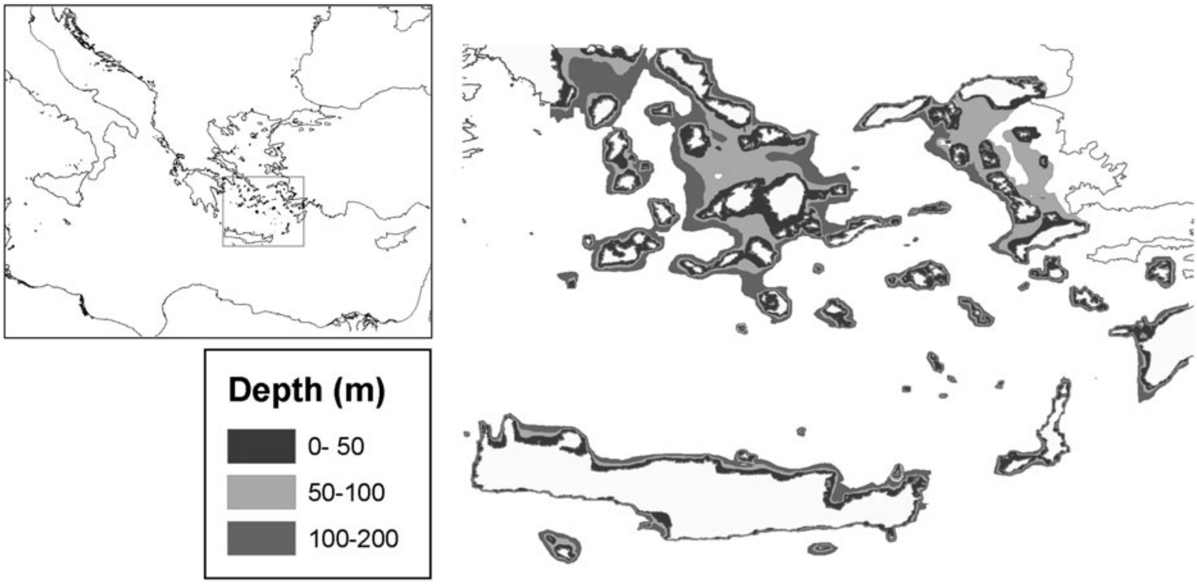

Fig. 1 Map of the examined area

of 60 stations distributed over the studied area. The data used for the purpose of this study comprise abundance indices by station, expressed in terms of kg per square km of swept area (kg/km^2).

For each species, the effect of depth on abundance was examined by means of Generalized Additive models (GAMs). GAMs, which are able to deal with non-linear relationships between a dependent variable and multiple predictors in the same model, are non-parametric generalizations of multiple linear regression that are less restrictive in assumptions about the underlying distribution of data (Hastie & Tibshirani, 1990). In GAMs, a pre-defined link function is related to predictor variables by scatterplot smoothers in lieu of least-squares fits. Based on the diagnostic residual plots of preliminary runs, we assumed a Gamma error structure model accompanied by a log-link function. The zero values have been excluded from the analysis, as their relatively high number did not allow proper modeling of the observed abundance variations. Apart from depth, the sampling year was also modeled to account for temporal fluctuations in stock abundance. Model fitting was accomplished by means of the “mgcv” package (Wood, 2004) under the R language environment (R Development Core Team, 2008) and statistical inference was based on the 95% confidence level.

At a next step, the relative (%) abundance by species and depth stratum (0–50, 50–100, 100–200, and >200 m) was estimated by grouping the GAM predicted estimates of abundance at depth. In addition, Geographic Information System (GIS) techniques were used to calculate the area within the zones defined by the 1.0 and 1.5 mile boundaries, respectively, for each depth stratum. Based on the above, the relative species abundance and thus the amount of resources available to the fishery under different management regimes was estimated by zone.

Results

GAM analysis revealed that the effect of depth was statistically significant for all species apart from *D. annularis*, while the effect of year was significant only in the case of *L. vulgaris* (Table 1). Plots of the standardized effect of depth on abundance indicated that the abundance of *M. barbatus* and *M. surmuletus* decreased linearly with increasing depth (smoothers were considered unnecessary by the “mgcv” algorithm and the GAM model dropped down to a linear model), while a rather monotonic pattern of decreasing abundance with depth was found for *L. vulgaris*,

Table 1 Analysis of deviance table for the applied GAMs by species

Species	Effect of year			Effect of depth			Deviance explained by the model
	df	*F*	*P*	df	*F*	*P*	
Boops boops	1	1.208	0.273	6.832	15.454	<0.001*	0.372
Diplodus annularis	1	2.578	0.115	1	2.857	0.098	0.079
Eledone moschata	1	0.058	0.810	8.378	12.161	<0.001*	0.349
Loligo vulgaris	3.223	2.138	0.047*	1.921	4.878	0.001*	0.192
Mullus barbatus	1.303	0.514	0.673	1	68.222	<0.001*	0.222
Mullus surmuletus	1.641	1.051	0.382	1.062	12.747	<0.001*	0.137
Octopus vulgaris	3.262	1.528	0.163	4.254	4.582	<0.001*	0.250
Pagellus erythrinus	1	3.374	0.068	8.725	7.235	<0.001*	0.274
Sepia officinalis	2.608	1.777	0.114	5.908	4.003	<0.001*	0.377
Spicara flexuosa	1.693	1.045	0.387	4.161	8.240	<0.001*	0.318
Spicara smaris	2.775	2.132	0.051	4.783	11.058	<0.001*	0.27

Asterisks indicate significant effects at the 0.05 confidence level

O. vulgaris, *S. smaris*, and *S. flexuosa*. The rest of the species had more complex polymodal depth distribution patterns (Fig. 2).

The estimates of relative species abundance by depth stratum revealed that the largest part (75–100%, depending on the species) of the populations of the examined species inhabit the continental shelf zone (0–200 m). Moreover, a significant part appears in more shallow depths, with percentages ranging from 14 to 30% and from 22 to 55% for the 0–50 and 50–100 m depth strata, respectively, (Table 2).

The GIS analysis of the topography of the area revealed that an increase of the trawling ban up to 1.5 NM from the coast would reduce by 22.41 and 11.12% the trawlable area of the 50–100 and 100–200 m depth strata, respectively, with reference to the current situation (Table 3). Based on this, and the estimated allocation of species by depth stratum (Table 2), the proportion of the resources not available to the fishery under different management regimes was calculated, assuming homogeneous species distribution in a given depth stratum (Table 4). Under the present management status (bottom-trawl fishing prohibition in depths less than 50 m and within 1 NM from the coast), more than 25% of the population is not accessible to the bottom trawlers for the majority of the species. With the additional 0.5 NM fishery ban, this amount increases by 20–80%, resulting in a total of 30–45% of inaccessible populations, depending on the species.

Discussion

It is well documented in the literature that depth plays an important role in determining the distribution and abundance patterns of marine populations (Macpherson, 2003; Reynolds, 2003; Katsanevakis & Maravelias, 2009), and depth is also a crucial driver for the composition of marine assemblages (Moranta et al., 1998; Tserpes et al., 1999; Demestre et al., 2000; Magnussen, 2002; Gaertner et al., 2005; Juan-Jordá et al., 2009). In line with those findings, our results clearly demonstrate the existence of statistically significant relationships between depth and abundance for all examined species apart from *D. annularis*, which is a species highly associated to the coastal zone and in the present case was not found in depths greater than 30 m. Taking into account that our sampling covered a depth range of 20–800 m, this explains why the depth-abundance relationship for this species was found not to be significant. For several commercially important species (e.g. *M. barbatus*, *P. erythrinus*, *O. vulgaris*, etc.), a large part of the population (over 50%) is found in depths up to 100 m, indicating that shallow waters of the continental zone are very important for fisheries targeting those species.

As depth determines, to a large extent, the distribution pattern of the species, it constitutes a variable of crucial importance for the spatial management of marine fisheries and should be taken into account when adopting relevant management schemes. In the case of areas such as the southern

Fig. 2 GAM derived standardized effect of depth on species abundance. The relative density of data points is shown by the "rug" on the *x*-axis

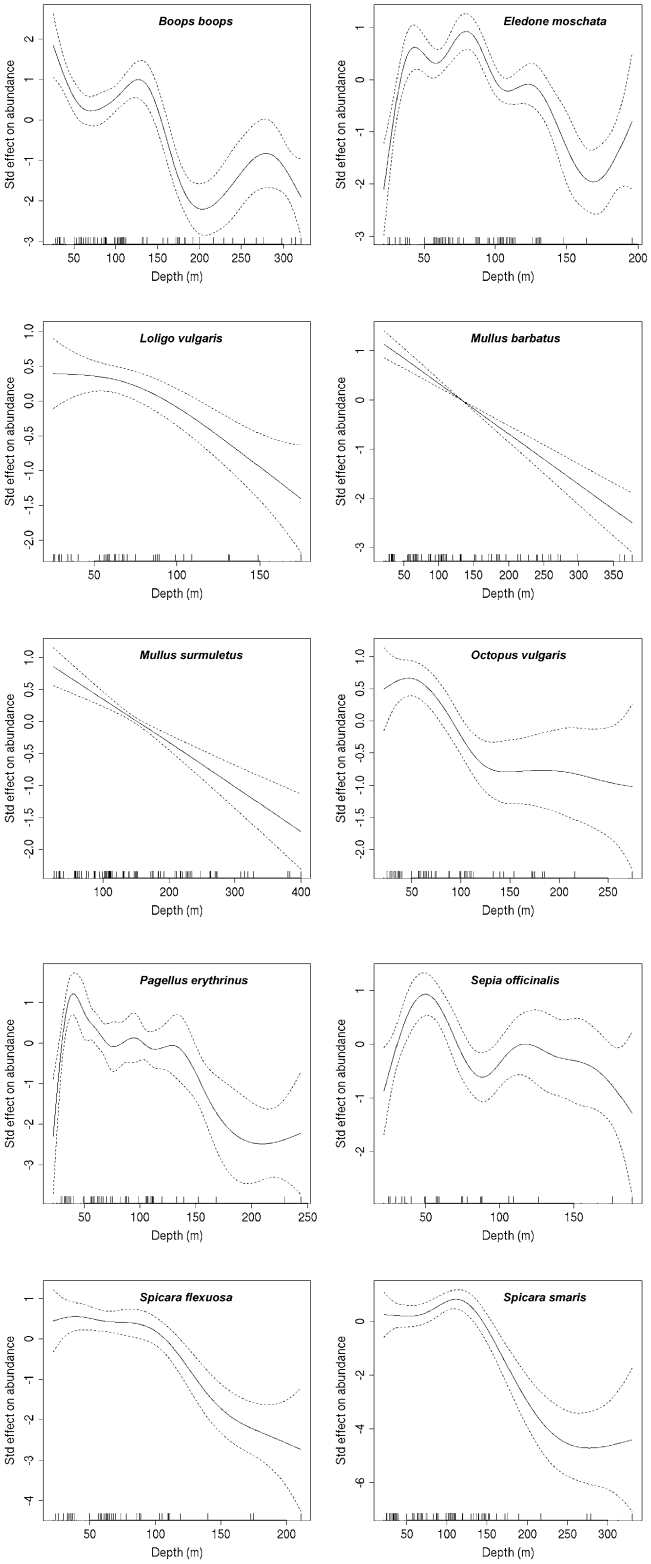

Table 2 Relative (%) GAM abundance estimates of the examined species by depth stratum

Species	Abundance (%)			
	0–50 m	50–100 m	100–200 m	>200 m
Boops boops	29.93 (8.46–51.40)	22.25 (13.30–31.20)	38.22 (19.55–56.89)	9.6 (1.92–17.38)
Eledone moschata	13.78 (8.11–19.45)	54.66 (35.14–74.17)	31.56 (17.83–50.71)	–
Loligo vulgaris	26.75 (7.43–46.08)	44.34 (15.89–72.79)	28.91 (7.66–50.15)	–
Mullus barbatus	23.25 (15.25–31.25)	31.92 (22.65–41.19)	30.57 (22.84–38.30)	14.26 (8.60–19.91)
Mullus surmuletus	16.92 (10.69–23.14)	26.38 (18.08–34.68)	32.29 (23.46–41.11)	24.42 (14.74–34.10)
Octopus vulgaris	23.04 (9.99–36.09)	35.62 (18.23–53.01)	25.86 (10.23–41.48)	15.48 (3.02–29.45)
Pagellus erythrinus	21.9 (8.84–34.96)	46.61 (21.10–72.13)	31.49 (7.81–56.17)	–
Sepia officinalis	23.56 (10.34–36.78)	36.91 (16.89–56.93)	39.53 (11.04–72.31)	–
Spicara flexuosa	26.98 (12.11–41.85)	48.55 (28.34–68.76)	23.4 (10.62–36.30)	1.06 (0.61–2.74)
Spicara smaris	14.82 (4.19–25.45)	36.34 (15.46–57.22)	47.75 (17.62–77.89)	1.09 (0.63–2.81)

Numbers in parentheses indicate the 95% confidence intervals of the corresponding estimates

Table 3 Total surface by depth stratum of the potentially accessible continental shelf fishing grounds under different management regimes

	Depth stratum (m)	Surface (km^2)	Remaining (%)
Total area	50–100	7826.83	
	100–200	7966.70	
Minus 1 NM from the shore (current situation)	50–100	7183.12	91.78
	100–200	7469.17	93.75
Minus 1.5 NM from the shore (proposal)	50–100	5573.71	71.21
	100–200	6638.61	83.33

Table 4 Estimated proportion (%) of species resources not available to the bottom-trawl fishery under different management regimes

Species	Current management	1.5 NM fishery ban
Boops boops	34.2 (10.8–57.5)	43.3 (15.9–70.6)
Eledone moschata	20.3 (12.1–28.7)	35.7 (21.8–50.6)
Loligo vulgaris	32.2 (9.2–55.2)	45.1 (13.5–76.7)
Mullus barbatus	27.8 (18.5–37.0)	38.2 (26.0–50.3)
Mullus surmuletus	21.1 (13.6–28.5)	30.5 (20.2–40.7)
Octopus vulgaris	27.6 (12.1–43.0)	38.3 (17.2–59.2)
Pagellus erythrinus	27.7 (11.0–44.4)	41.4 (16.6–66.4)
Sepia officinalis	29.1 (12.4–45.9)	41.5 (17.3–66.4)
Spicara flexuosa	32.4 (15.1–49.7)	45.7 (22.5–68.9)
Spicara smaris	20.8 (6.5–35.0)	34.0 (11.9–56.1)

Numbers in parentheses indicate the 95% confidence intervals of the corresponding estimates

Aegean Sea, with a narrow continental shelf, spatial fishery prohibitions that do not consider the depth parameter may seriously affect the viability of certain fisheries. In the present case, the enforcement of the 1.5 NM fishery ban would drastically decrease (over 30%) the availability to the bottom trawlers of fishery grounds along the continental shelf, a zone inhabited by several important target species. It will also significantly increase (20–80%) the proportion of the populations that are inaccessible to this gear. Provided that the fishing pressure caused by bottom trawlers in the coastal zone will not be replaced by other fisheries, the introduction of the new ban would be beneficial for the stocks, and consequently for the fishery, in the medium to long-term. In the short-term, however, significant catch reductions are expected for several species. Furthermore, the extension of the spatial trawling prohibition may favor the inclusion of unmapped coralligenous habitats that usually host important fish communities (Georgiadis et al., 2009; Ordines & Massutí, 2009; Ordines et al., 2009), into the protected zone.

However, if such a ban is not accompanied by a capacity reduction of the bottom-trawl fishery (e.g., number of vessel licenses), it would result in higher competition for fishery resources in deeper areas; thus increasing fishery pressure on stocks inhabiting the continental slope (e.g., hake, shrimps). Taking into account that currently about 34% of the commercial hauls in the studied area are accomplished within 1.5 NM off the coast (Skarvelis et al., 2009), it is expected that a considerable proportion of the fishing effort will be shifted to deeper living resources. The impact of such a change in the fishery exploitation pattern needs to be evaluated. In any case, management planning should ensure that any further bottom-trawling prohibitions will not result in the replacement of trawling with other fishing activities that maintain high fishing mortality rates.

Although there are no assessment studies for the exploited stocks in the area, the lack of significant temporal variation suggests that the populations are in relative stability. Significant abundance variations over time were found only for squid which is a species with a short life span, governed by an r-strategy life history and subject to wide population fluctuations (Natsukari & Komine, 1992; Guerra & Rocha, 1994); thus temporal abundance variations are not surprising. The general overall stability could perhaps be linked to an "overfishing steady state" situation that has been debated for the whole Mediterranean (Lleonart & Maynou, 2003). However, the fact that a significant part of the examined stocks is currently unavailable to the bottom-trawl fishery under the existing legislation (no fishing up to 50 m depth and within 1 NM from the coast) may also contribute to the aforementioned population stability.

Our estimates may to a certain extent be biased, as they are based on an annual survey; thus ignoring intra-annual variability in species distribution patterns. Our approach, however, is the first attempt to evaluate the impact that can be estimated to occur from the enforcement of the 1.5 NM fishery ban. Further studies that take into account the seasonal variability in species distribution patterns may provide more precise evaluations of the full impact of the proposed spatial management regime.

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