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Research Note

Comanagement Practices Enhance Fisheries in Marine Protected Areas

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Abstract: *Fishing activities worldwide have dramatically affected marine fish stocks and ecosystems. Marine protected areas (MPAs) with no-take zones may enhance fisheries, but empirical evidence of this is scant. We conducted a 4-year survey of fish catches around and within an MPA that was previously fully closed to fishing and then partially reopened under regulated comanaged fishing. In collaboration with the fishers and the MPA authority, we set the fishing effort and selected the gear to limit fishing impact on key fish predators, juvenile fish stage, and benthic communities and habitats. Within an adaptive comanagement framework, fishers agreed to reduce fishing effort if symptoms of overfishing were detected. We analyzed the temporal trends of catch per unit of effort (CPUE) of the whole species assemblages and CPUE of the four most valuable and frequent species observed inside the opened buffer zone and outside the MPA investigated. After the comanaged opening, CPUE first declined and then stabilized at levels more than twice that of catches obtained outside the MPA. Our results suggest that working closely with fishers can result in greater fisheries catches. Partial protection of coastal areas together with adaptive comanagement involving fishers, scientists, and managers can effectively achieve conservation and fishery management goals and benefit fishing communities and alleviate overfishing.*

Keywords: coastal fisheries, eco sustainability, fishing catch, marine protected areas, marine reserves, Mediterranean Sea, time-series analysis

Las Prácticas de Co-Manejo Enriquecen las Pesquerías en Áreas Marinas Protegidas

Resumen: *Las actividades pesqueras en todo el mundo han afectado dramáticamente las existencias de peces y ecosistemas marinos. Las áreas marinas protegidas (AMP) con zonas sin captura pueden incrementar las pesquerías, pero la evidencia empírica es escasa. Durante 4 años realizamos un estudio de las capturas de peces alrededor y dentro de una AMP que previamente había estado totalmente cerrada a la pesca y posteriormente fue reabierta parcialmente para pesca co-manejada regulada. En colaboración con los pescadores y la autoridad de la AMP, fijamos el esfuerzo de captura y seleccionamos las artes de pesca para limitar el impacto de la pesca sobre peces depredadores clave, estadios juveniles y comunidades y hábitats bentónicos. En un marco de co-manejo adaptativo, los pescadores acordaron reducir el esfuerzo de pesca si se detectaban síntomas de sobrepesca. Analizamos las tendencias temporales de captura por unidad de esfuerzo (CPUE) de todos los ensambles de especies y por CPUE de las especies más valiosas y frecuentes observadas dentro de la zona de amortiguamiento y afuera de la AMP investigada. Después de la apertura co-manejada, la CPUE primero declinó y luego se estabilizó en niveles más del doble que los de la captura afuera de la AMP estudiada. Nuestros resultados sugieren que el trabajo conjunto con los pescadores puede resultar en mayores capturas. La protección parcial de las aguas costeras junto con el co-manejo adaptativo involucrando a pescadores, científicos y manejadores pueden lograr la conservación y las metas de manejo de las pesquerías y beneficiar a las comunidades de pescadores y aligerar la sobrepesca.*

Palabras Clave: análisis de series de tiempo, áreas marinas protegidas, captura pesquera, eco sustentabilidad, Mar Mediterráneo, pesquerías costeras, reservas marinas

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Introduction

Fishing may have dramatic effects on species, habitats, and ecosystems (Botsford et al. 1997; Jackson et al. 2001; Worm et al. 2006), yet marine protected areas (MPAs) that include marine reserves (i.e., no-take zones) can counteract overfishing (Claudet et al. 2008) and enhance yields outside their borders (Roberts et al. 2001). Effects of MPAs on fisheries may be attributable to ecological mechanisms (Sale et al. 2005; García-Charton et al. 2008) and management practices (Castilla 1999; Guidetti et al. 2008). Greater densities and sizes of fishes in reserves can induce spillover of adults and exportation of eggs and larvae across their boundaries (Harmelin-Vivien et al. 2008), and adoption of sustainable fishing practices in the buffer zones surrounding the reserves can limit detrimental fishing effects and enhance yields and profits (Pauly et al. 2002). Theoretical model-based studies have analyzed the impacts of biology and management (White & Kendall 2007), but empirical evidence is scant and uncertainty high.

We sought to assess whether local fishers may benefit from a comanagement approach that involves fishers, MPA managers, and scientists, and to determine whether conservation goals could also be compatible with comanagement of fishing. We collected catch data over 4 years in the buffer zone of an MPA surrounding the no-take zone and in the surrounding fishing ground outside the MPA. We designed a comanagement plan and fishing protocol with the MPA authority and local fishers to support fishers' incomes and limit fishing impacts, and we tested the effectiveness of this shared fishing protocol in previously closed areas of an Italian MPA.

Methods

MPA Buffer Zone and Adaptive Management

The Torre Guaceto MPA is in southeastern Italy along the southern Adriatic coast (Mediterranean Sea; Fig. 1). It was formally established in 1991, but enforcement became effective around 2000. The entire MPA covers 2227 ha and was subdivided into two zones before our experiment in 2005: (1) a no-take and no-access zone (179 ha) and (2) a no-take and access buffer zone (2048 ha). Therefore, from about 2000 to 2005, the entire MPA was a fully no-take zone and effectively protected from any extractive activity by the MPA staff and the local maritime police. The effectiveness of the enforcement was reflected in a clear increase in fish density and size (Guidetti 2006). In 2005, we began our comanagement experiment (see details subsequently) and opened to fishing a sector (1885 ha) of the buffer zone. The remaining portion of the no-take and access buffer zone, and the no-take and no-access zone remained unfished (342 ha) (Fig. 1).

Before the opening, we developed a protocol with local fishers and the MPA authority aimed at regulating fishing effort to avoid overfishing of local resources in the newly opened buffer zone of the MPA. We previously conducted a pilot study to select fishing gear (net type, length, and mesh size) to limit impact on fish species preying on sea urchins (to avoid ecosystem collapse, i.e., the transition from macroalgal beds to barrens caused by overgrazing by sea urchins [*Paracentrotus lividus* and *Arbacia lixula*]; Sala et al. 1998; Guidetti 2006); juvenile fish stages; and benthic communities and habitats. The accepted fishing gear for all fishers was a trammel net of 1200 m maximum length with minimum mesh size of 2.8 cm. This net was used inside and outside the MPA to make

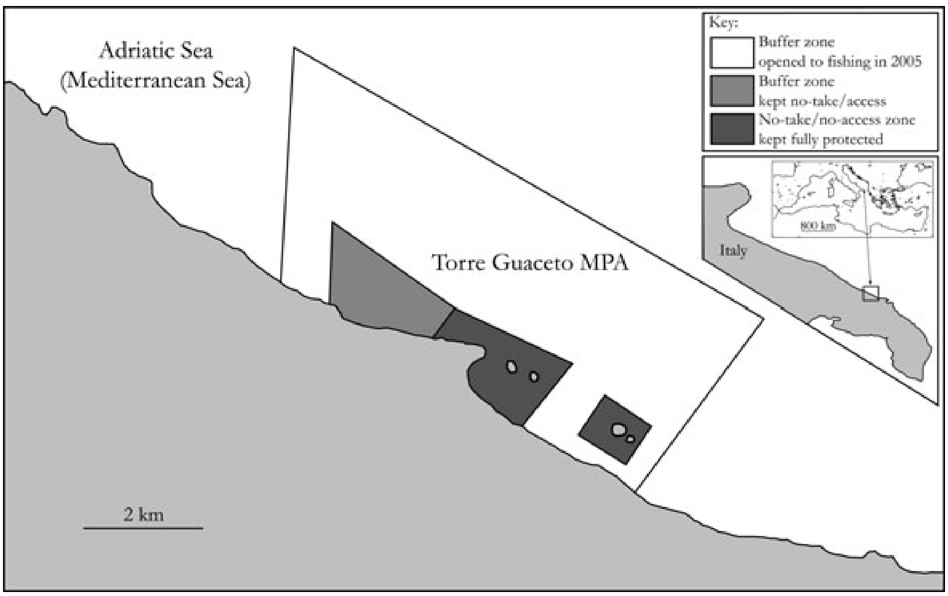

Figure 1. Location of the study area and Torre Guaceto Marine Protected Area.

comparisons possible. The fishing fleet involved in the experiment was limited to four boats (with total length and engine power ranging from 5.42 to 6.90 m and from 13.60 to 28.30 kW, respectively), which represented 40–50% of the initial local fishing fleet, and was authorized to fish inside the MPA once per week. We set these initial criteria (e.g., fishing frequency and mesh size) without previous data (i.e., empirical evidence or model projections) in order to reach a consensus derived from fishers' methods and customs and obtain their agreement on the regulated fishing effort within the opened sector. Besides, fishers were involved in an adaptive comanagement framework as they also agreed to consider reducing their fishing effort or change selectivity of their gear (e.g., using nets with larger mesh) if symptoms of overfishing were detected. We organized bi-monthly meetings with fishers and MPA managers to discuss progresses of the experiment.

Fishing inside the MPA started on 22 January 2005, and we collected data up to 10 April 2008. Experimental fishing outside the MPA started on 2 February 2005 and lasted until 14 March 2008. All catch data from all fishing trips were obtained. All nets were towed between 18:00 and 06:00. By *experimental fishing*, we mean fishing activities conducted under the above specifications in the opened MPA buffer zone and surrounding fishing ground. Fishers involved in our comanagement experiment agreed to use the same type of net inside and outside the MPA to make data comparable, and they gave us the coordinates of their fishing locations. The surrounding fishing ground, however, was also regularly fished by other fishers using other gears. Outside the MPA, calculated catch per unit of effort (CPUE) are thus relative to the specific gear used within and outside the MPA.

Even though published maps of habitat types were available only for the within-MPA area (Fraschetti et al. 2005), observations of aerial photographs and direct inspections underwater suggest that the habitat characteristics were similar along the coast of the study area inside and outside the MPA. That habitat characteristics or others factors possibly differed inside and outside the MPA probably did not confound our results is also supported by data collected before the MPA was established and enforced. Before the MPA was established and protected, rocky reefs were dominated by sea urchins, mostly represented by barrens, and are now largely dominated by macroalgae (Guidetti 2006). As previously reported, moreover, a clear increase in fish density and size occurred after the MPA establishment and enforcement (Guidetti 2006). In addition, CPUE obtained from the MPA area, before it was established, were similar to the values we report in this study for the fishing ground surrounding the MPA (P.G., unpublished data). Potential differences detected between the MPA and the surrounding fishing ground are therefore mostly attributable to protection.

Data Analyses

Fishing effort differed on the basis of the net length used by each boat. We standardized the data for 1000 m of net. We analyzed trends in CPUE of all (caught) species and CPUE of the four most frequent species in the catches inside and outside the MPA, for a total of 10 time series. Striped red mullets (*Mullus surmuletus*), largescaled scorpionfishes (*Scorpaena scrofa*), east Atlantic peacock wrasses (*Symphodus tinca*), and common octopuses (*Octopus vulgaris*) represented more than 55% and 40% of mean CPUE inside the opened sector and outside of the MPA, respectively (Table 1). The striped red mullet is the most-caught species and most-important species in terms of economic revenue because of its high market value. Due to bad weather and sea conditions, time series of catch data were irregular, with average time steps of 16 and 25 days for fishing activities inside and outside the MPA, respectively. We regulated the 10 time series with a linear method and a tolerance window of one day. To obtain the appropriate regulated time series, we considered the number of observations, the interval between two successive observations, and the position of the first observation in the regulated time series that optimized the number of matching observations within the tolerance window and that optimized the number of observations that coincided exactly with the initial values. We obtained time steps of 13 and 14 d for inside and outside the MPA, respectively.

Time series are often the result of a superposition of several effects that can be decomposed. Typically, a long-term general trend is superimposed on one or more cycles (seasonal, lunar, circadian, or other) and a randomly fluctuating background series. To detect the presence of cyclical trends we estimated the autocorrelation and spectral density of the time series (Venables & Ripley 2002). No cyclical trends occurred for any of the time series.

We expected a stabilization to occur in the catches inside the opened sector of the MPA as a result of the comanaged regulated fishing pressure. To test for such a trend, we defined a logistic function with a lower asymptote that was not zero:

$$A_{\min} + (A_{\max} - A_{\min}) \times \frac{\exp\left[b(x - x_{\mathrm{mid}})\right]}{\{1 + \exp\left[b(x - x_{\mathrm{mid}})\right]\}},$$

where $A_{\max}$ and $A_{\min}$ are the upper and lower asymptotes, respectively, x_{mid} is the inflection point of the curve, b is the scale parameter, and x is the CPUE time series. We fitted this function with nonlinear least-square estimates for CPUE series inside the MPA. If a fit was impossible for a given series, we fitted a linear regression model. Outside the MPA, catch trends were not expected to decrease and then stabilize because this zone was also subject to exploitation regulated by national laws that did not

Table 1. Mean percent catch composition over time outside and inside the area opened to fishing after 5 years of effective full protection.

Species	Outside	Inside	Species	Outside	Inside
Anguilla anguilla	0.00	0.04	*Pagellus erythrinus*	3.30	3.80
Apogon imberbis	0.00	0.00	*Pagrus pagrus*	3.82	2.75
Boops boops	0.06	0.21	*Palinurus elephas*	0.00	0.14
Bothus podas	0.00	0.00	*Pegusa lascaris*	0.10	0.02
Chelidonichtys lastoviza	0.06	0.01	*Penaeus kerathurus*	0.01	0.01
Chelidonichtys lucernus	0.05	0.02	*Phycis phycis*	7.43	3.76
Conger conger	2.50	1.23	*Sarda sarda*	1.94	1.06
Coris julis	0.06	0.01	*Sarpa salpa*	0.36	0.33
Dasyatis pastinaca	0.14	1.20	*Sciaena umbra*	0.52	1.75
Dentex dentex	2.82	2.64	*Scillarides arctus*	0.01	0.00
Dicentratus labrax	0.00	0.13	*Scillarides latus*	0.16	0.40
Diplodus annularis	1.20	0.92	*Scomber scomber*	0.04	0.54
Diplodus puntazzo	0.04	0.09	*Scorpaena maderensis*	0.00	0.00
Diplodus sargus	2.24	1.41	*Scorpaena notata*	1.25	0.29
Diplodus vulgaris	1.86	0.87	*Scorpaena porcus*	0.81	1.95
Eledone moschata	1.51	0.42	*Scorpaena scrofa*	7.06	15.29
Illex coindetii	0.00	0.04	*Sepia officinalis*	10.41	5.23
Labrus merula	1.22	1.15	*Seriola dumerili*	0.32	0.14
Labrus mixtus	0.00	0.10	*Serranus cabrilla*	0.11	0.08
Labrus viridis	0.24	0.12	*Serranus scriba*	1.71	1.22
Lichia amia	0.00	0.01	*Solea* sp.	0.12	0.26
Lithognathus mormyrus	0.10	0.00	*Solea vulgaris*	0.00	0.05
Liza aurata	3.44	0.50	*Sparus aurata*	0.27	0.56
Liza ramada	0.00	0.35	*Sphyraena sphyraena*	0.15	0.00
Loligo vulgaris	0.91	0.23	*Spondyliosoma cantharus*	1.22	1.08
Merluccius merluccius	0.03	0.03	*Squilla mantis*	0.11	0.06
Monochirus hispidus	0.00	0.00	*Symphodus mediterraneus*	0.00	0.00
Mugil cephalus	0.77	1.67	*Symphodus ocellatus*	0.01	0.00
Mugilidae spp.	0.00	1.16	*Symphodus tinca*	6.24	8.33
Mullus barbatus	0.00	0.05	*Torpedo marmorata*	1.71	0.93
Mullus surmuletus	17.58	24.68	*Torpedo torpedo*	0.00	1.21
Muraena helena	1.09	0.30	*Trachinus Araneus*	0.00	0.06
Myliobatis aquila	0.09	0.08	*Trachurus mediterraneus*	0.41	0.04
Oblada melanura	0.19	0.27	*Trachurus* spp.	0.00	0.03
Octopus vulgaris	9.87	7.60	*Umbrina cirrosa*	0.87	0.20
Pagellus acarne	0.28	0.08	*Uranoscopus scaber*	0.36	0.81
			Zeus faber	0.82	0.02

included comanagement. We assessed the trends in CPUE series outside the MPA by fitting linear regression models.

To produce smoothed time series, we filtered the regular time series with a moving average (order = 2, and window centered on each observation for all 10 time series). All analyses were conducted with R (R Development Core Team 2006).

Results

Immediately after opening the MPA buffer zone to fishing, the average CPUE of all species inside the MPA was approximately 60 kg/km, with values ranging from 22 to 115 kg/km (Fig. 2a). Catch then declined and stabilized 3 years later to an average of approximately 20 kg/km (Table 2; significant lower asymptote). The CPUE of all species outside the MPA never exceeded 21 kg/km (average 9.6 kg/km) (Fig. 2b) and had a significant decreasing trend (Table 2).

The CPUE of striped red mullets within the MPA ranged between 1.2 and 43.7 kg/km. There was, however, a single CPUE peak of 73.6 kg/km (Fig. 2c). The CPUE decreased slowly and stabilized around 6 kg/km 3 years after the initial opening (Table 2; significant lower asymptote). Outside the MPA, CPUE of the striped red mullets ranged between 0 and 5.6 kg/km (Fig. 2d) and followed a decreasing trend (Table 2).

The CPUE of largescaled scorpionfishes ranged between 0 and 30 kg/km after the opening of the MPA buffer zone, and over time there were three CPUE peaks, each one progressively less than the first (Fig. 2e). Despite quite substantial fluctuations, CPUE seemed to stabilize 2 years after opening of the MPA sector (Table 2; significant lower asymptote). Outside the MPA, CPUE did not exceed 2.8 kg/km (Fig. 2f) and followed a decreasing trend (Table 2).

Inside the opened sector of the MPA, CPUE of east Atlantic peacock wrasses fluctuated between 0 and 20 kg/km (Fig. 2g), and no model—neither logistic (Table 2)

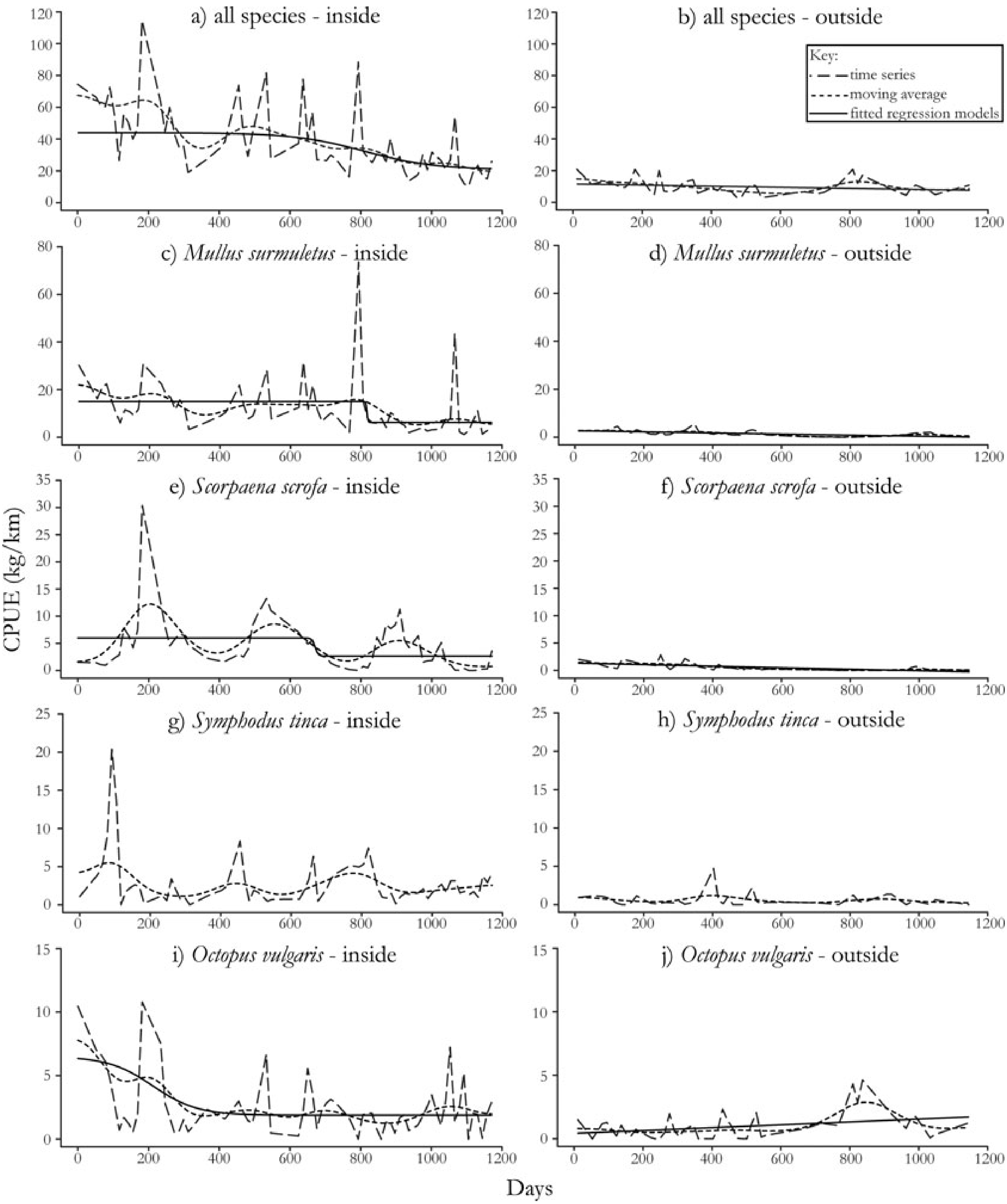

Figure 2. Catches per unit of effort (CPUE) series of all and the three most abundant species inside and outside a marine protected area opened to comanaged regulated fishing in January 2005 (day 0), after 5 years of effective full protection. Moving average filtered values and fitted curves of the regression models are superimposed. The absence of fitted vales (g, h) indicates the absence of a significant trend (see Table 2 for details on the models).

Table 2. Parameter estimates and tests for the nonlinear fit of the nonzero lower asymptote logistic function on catch per unit of effort (CPUE) inside the sector of the marine protected area opened to fishing after 5 years of effective full protection and for the linear-regression model fit on CPUE outside the marine protected area.

CPUE	*Parameters*	*Estimate*	*SE*	t	p
Inside sector of marine protected area opened to fishing					
all species[a]	A_{min}	20.791	8.680	2.395	0.019
	x_{mid}	809.554	129.613	6.246	<0.001
	b	−0.010	0.010	−1.040	0.301
Mullus surmuletus[a]	A_{min}	6.256	1.950	3.208	0.002
	x_{mid}	816.701	370.434	2.205	0.030
	B	−0.662	106.684	−0.006	0.995
Scorpaena scrofa[a]	A_{min}	2.658	0.826	3.216	0.002
	x_{mid}	670.179	31.390	21.350	<0.001
	B	−0.218	1.029	−0.212	0.833
Symphodus tinca[b]					
Octopus vulgaris[a]	A_{min}	1.881	0.292	6.445	<0.001
	x_{mid}	211.903	35.306	6.002	<0.001
	b	−0.016	0.008	−2.012	0.047
Outside marine protected area					
all species[c]	intercept	11.598	0.931	12.451	<0.001
	days	−0.003	0.001	−2.486	0.015
Mullus surmuletus[c]	intercept	2.706	0.202	13.394	<0.001
	days	−0.002	0.000	−7.611	<0.001
Scorpaena scrofa[c]	intercept	1.338	0.100	13.317	<0.001
	days	−0.001	0.000	−9.261	<0.001
Symphodus tinca[c]	intercept	0.792	0.160	4.941	<0.001
	days	0.000	0.000	−1.533	0.129
Octopus vulgaris[c]	intercept	0.426	0.217	1.965	0.053
	days	0.001	0.000	3.464	0.001

[a]*Achieved convergence tolerances: 9.537e-06, 9.515e-06, 8.68e-06, and 6.481e-06, respectively.*
[b]*Model could not be fitted (see text for details).*
[c]*Adjusted* R^2*: 0.060, 0.413, 0.511, 0.017, and 0.1196, respectively.*

nor linear ($p = 0.228$)—was adjustable on the series. The situation was similar outside the MPA (Table 2). The CPUE fluctuated between 0 and 4.7 kg/km (Fig. 2h), and there was no significant decreasing trend (Table 2).

The CPUE of common octopus ranged from 0 to 10.8 kg/km (Fig. 2i) and decreased after the opening to reach an average stabilized value of 1.9 kg/km 1 year after opening of the sector (Table 2; significant lower asymptote). Outside the MPA, CPUE did not exceed 4.6 kg/km (Fig. 2j) and tended to increase over time (Table 2).

Discussion

Temporal trends in catch inside and outside the MPA provided two completely different pictures. After 3 years of comanaged exploitation, CPUE of all species and CPUE of the most common and valuable species within the MPA approached values approximately twice those obtained outside. In other situations in which an MPA was opened after full protection, in the absence of comanagement, CPUE and fish densities decreased without stabilizing (e.g., Alcala et al. 2005; Ferraris et al. 2005). Our comanagement target was to maintain catch levels. We sought to accomplish this target by adjusting fishing effort if necessary. As more data will be collected over time to complement the CPUE time series, we will keep assessing the permanence of the average asymptotic values. Thus, if CPUE shows a negative trend in the future, changes (i.e., a decrease) in fishing effort will be discussed with the fishers for potential reductions in their fishing effort.

According to our results, opening a sector of an MPA to benefit fisheries requires that the following be in place: effective enforcement; determination that fish density and size are increased before fishing can be resumed; and an adaptive comanagement plan. Our results suggest that partial protection of coastal areas together with an adaptive comanagement plan that involves fishers, scientists, and managers may benefit fishing communities and reduce overfishing. Incorporating fishers' input, in particular, alleviates their skepticism toward scientists, increases the likelihood they will respond positively to marine reserves, and can be one of the most important criteria for successful fisheries management. Our comanagement approach, an alternative to top-down approaches, could be further improved by catch-share practices (Costello et al. 2008), which give defined property rights over defined areas and exploit the multiple economic niches of fishers (e.g., assistance to divers; Gelcich et al. 1995) to further alleviate overfishing.

Although our project is probably unique in having an explicit adaptive comanagement component, in other regions effectively managed MPAs reduced local fishing effort and allowed local fishery recovery (McClanahan & Kaunda-Arara 1996). In addition, according to our results, fisher involvement in the development of collaborative projects and proper management of no-take areas are essential attributes for effective resource management, which should embrace ecological, economical and socio-cultural components (Mascia 2003). These attributes should be combined to achieve the multiple goals of sustainable fisheries and marine ecosystem conservation (McClanahan et al. 2006; Gelcich et al. 2008). Moreover, assessment and dissemination of positive effects of MPAs on local human communities are crucial to enhance social support of the use of MPAs. In several regions of the world, the perception or the direct experience of positive effects of an MPA strongly enhanced the MPA's performance and success (e.g., Pollnac et al. 2001; Kritzer 2004; Gelcich et al. 2008).

Our results illustrate that fisheries comanagement within MPAs may enhance collaborative approaches among fishermen thus reducing the usual strong competition for shared fishing resources (the so-called "race to fish"). This is an important step to increase fishers' awareness towards fisheries sustainability, which is an essential attribute for social acceptance and success of MPAs

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