

Effects of trawling on fish and invertebrates from deep-sea coral facies of *Isidella elongata* in the western Mediterranean

FRANCESC MAYNOU AND JOAN E. CARTES

Institut de Ciències del Mar (CSIC), Psg. Marítim de la Barceloneta 37-49, 08003–Barcelona, Spain

Deep-water corals are known to provide essential habitat for fish and invertebrates along the continental slope in different areas of the world, offering prey to coral predators, protection or attachment substrate to other suspension feeders. In the Mediterranean Sea the coral Isidella elongata (Esper, 1788) characterizes a facies of bathyal compact mud substrates between 500 and 1200 m depth. Based on 4 experimental surveys carried out between 1985 and 2008, we obtained quantitative data on the fauna associated with live coral stands. We show that species richness of invertebrates and crustaceans, as well as abundance and biomass of crustaceans, is higher in areas with large stands of the coral. Some commercial fishery species are also more abundant or reach larger sizes in areas with high density of the coral, particularly the red shrimps Aristeus antennatus (Risso, 1816) and Plesionika martia (A. Milne Edwards, 1883). Trawling over I. elongata facies causes direct impacts on the biological assemblages by removing the habitat-forming corals, decreasing invertebrate species diversity and negatively affecting fisheries production in the long term.

Keywords: *Isidella elongata*, deep-sea corals, trawl fisheries, ecological impact, *Aristeus antennatus*, Mediterranean Sea

Submitted 18 March 2011; accepted 9 August 2011; first published online 21 October 2011

INTRODUCTION

It is well known that bottom trawling has a paramount role in the degradation of benthic coastal and deep-water ecosystems, by directly removing large amounts of biomass or, indirectly, by jeopardizing ecosystem functioning (Watling & Norse, 1998; Roberts, 2002; Colloca *et al.*, 2004; Gray *et al.*, 2006). In the North Atlantic European margins, the impact of human activities on deep-water coral reefs has been studied in relation to the effects of bottom trawling on reefs dominated by *Lophelia pertusa* (Rogers, 1999; Fosså *et al.*, 2002). These studies show that bottom trawling has a negative impact on the reefs and associated species by directly destroying or removing them, but also indirect impacts due to increased resuspension of bottom sediment, which damages filter feeding organisms such as corals by siltation (clogging). Additionally, long-term indirect effects include the removal of protection or feeding places for slope-dwelling species and, in general, an impoverishment of continental-slope ecosystems (as with their tropical counterparts: Watling & Norse, 1998; Roberts, 2002). The recovery of the direct and indirect damage produced by bottom-trawling on these habitats may take decades or centuries, according to the slow growth rates of deep-water corals (few to several mm per year: Wilson, 1979; Andrews *et al.*, 2002; Fosså *et al.*, 2002).

Deep-water corals in the subclasses Hexacorallia (mainly scleractinians) and Octocorallia (mainly gorgonaceans) are known to provide essential habitat for fish and invertebrates

along the continental slope in different areas of the world (Andrews *et al.*, 2002; Fosså *et al.*, 2002; Etnoyer & Morgan, 2003; Freiwald *et al.*, 2004; D'Onghia *et al.*, 2010). Deep-water corals form three-dimensional structures on the sea-bottom, in an otherwise relatively homogeneous and flat landscape, either by forming reef structures (such as the scleractinian *Lophelia pertusa* in the North Atlantic) or as 'coral meadows', where individual corals rise from the bottom forming tree-like or candelabra-like structures (many species of gorgonacean corals). Krieger & Wing (2002) showed that gorgonacean *Primnoa* spp. in the Gulf of Alaska provide essential habitat to fish and invertebrates by: (i) acting as feeding places for their predators (sea stars); (ii) providing protection to large fauna (rockfish, crabs and shrimps); or (iii) providing an attachment substrate to other suspension feeders (basket stars, anemones and sponges). Husebø *et al.* (2002) reported that the abundance of commercial fish was higher and individual size was larger in reef habitats built by *Lophelia pertusa* when compared with surrounding areas in Norwegian waters, suggesting that deep-water coral reefs provide feeding habitat for commercial species. In the central-eastern Mediterranean, D'Onghia *et al.* (2010) showed that the relict white coral banks composed of *Lophelia* and *Madrepora* harbour large densities of reproducing individuals of certain fish species (rockfish and blackspot seabream), while at the same time being nursery areas for the deep-water shark *Etmopterus spinax* and some important commercial fish species such as hake. Gage & Tyler (1992, pp. 212–214) suggested a positive relationship between habitat complexity and species diversity, hence, in the bathyal domain, habitats dominated by corals (reef-building scleractinians or solitary gorgonaceans) would provide patches of high-diversity habitats in a relatively homogeneous environment of low diversity.

Corresponding author:

F. Maynou

Email: maynouf@icm.csic.es

For example, Mastrototaro *et al.* (2010) recently showed that the white coral bank off Santa Maria di Leuca Cape (central-eastern Mediterranean) represents a biodiversity 'hot-spot' of the Mediterranean bathyal domain.

Deep-water gorgonacean corals of the family Isidiidae (with 138 known species) are cosmopolitan, occurring mainly in deep-waters (200 to 1500 m depth). Locally, they form large, single-species stands that dominate communities on soft-bottom sediments ('coral meadows'). Branching isidid corals can reach 3 m length (Krieger & Wing, 2002) and they are long lived (several decades in *Primnoa resedaeformis*: Andrews *et al.*, 2002). In the Mediterranean Sea *Isidella elongata* (Esper, 1788) characterizes a facies of bathyal compact mud substrates between 500 and 1200 m depth on relatively flat bottoms with slope <5% (Péres, 1967; Bellan-Santini, 1985; Laubier & Emig, 1993). *Isidella elongata* is a near-endemic to the Mediterranean Sea, reaching the adjacent Atlantic Ocean in the Ibero-Moroccan Gulf (Grasshoff, 1988, 1989).

Among species reaching their maximum abundance in bottoms inhabited by *I. elongata*, the deep-water red shrimps *Aristeus antennatus* and *Plesionika martia* are commercially important and represent a prime target of large trawlers, due to the high price fetched (Maynou *et al.*, 2006). The activity of trawlers removes colonies of this rather long and rigid gorgonacean. The effects of bottom-trawling on biological diversity and production of this biota are unknown, although, according to studies of impact on benthic communities by trawling on shelf habitats (Jennings *et al.*, 2001; Gray *et al.*, 2006) a decrease in biodiversity, along with a parallel decrease in production and increase in the production/biomass ratio (P/B) by elimination of larger specimens can be expected.

Based on four extensive scientific trawl surveys carried out between 1985 and 2008 we present data on the distribution of *I. elongata* in the north-western Mediterranean and on the fish and invertebrate species associated with this habitat. The objectives of this study are: (i) to provide quantitative data on the fish and invertebrate assemblages associated with *I. elongata* habitats; (ii) to investigate the effect of bottom-trawling on the community characteristics (species richness and species composition); and (iii) to enumerate the main fishery species of this habitat.

MATERIALS AND METHODS

Four experimental trawl cruises (BATIMAR: September 1985 and July 1988; ZONAP: May 1992; GEODELTA: April 1994; and BIOMARE: June 2007, February 2008) were conducted along the continental slope (depths sampled: 85–2253 m) of the north-western Mediterranean aboard RV 'García del Cid', where the entire benthic faunal assemblage was analysed. The study area comprised the continental margin of the Iberian Peninsula around latitude 41°N and longitudes 1°–3°E (Figure 1). A total of 189 trawl hauls were performed and 20 hauls yielded live *I. elongata* colonies. The area swept by each trawl haul was 0.022 to 0.033 km². The trawl used in the OTSB-14 model, commonly employed in deep-sea mega-faunal studies in Europe, was fitted to a 6 mm stretched mesh codend, with 8-m long bridles and 1.2 m vertical opening. Decapod crustaceans and fish were identified to species level, counted and weighed. Other invertebrates were

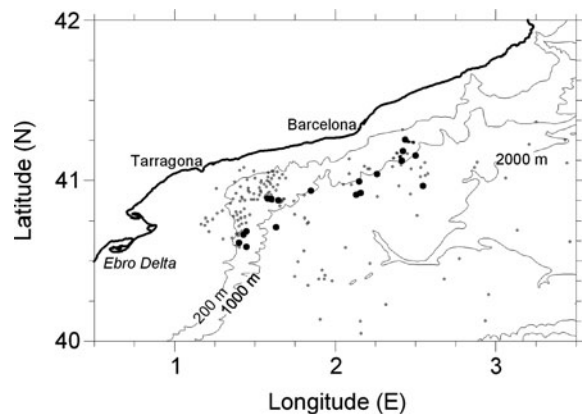


Fig. 1. Map of the study area showing the location of 189 trawl hauls conducted along 4 trawl surveys between 1985 and 2008. Filled circles indicate the presence of live *Isidella elongata* colonies. These were recovered between 418 and 1656 m depth.

identified to the lowest practical taxonomic level (species, genus or family), but could not always be counted or weighed.

The effect of *I. elongata* biomass (kg/km²) on the faunal assemblage in the 20 hauls yielding *I. elongata* was analysed statistically by means of non-parametric regression techniques, using generalized additive models (GAMs: Hastie & Tibshirani, 1986) to compare species richness (S), abundance (number of individuals/km²), biomass (kg/km²) and mean size of individuals (g) with log-transformed biomass of *I. elongata*. The comparison was made separately for decapod crustaceans, fish and other invertebrates. Additionally, the abundance, biomass and mean size of the species of commercial fishery interest were also tested: the decapod crustaceans *Aristeus antennatus*, *Geryon longipes* and *Plesionika martia*, and the fish *Phycis blennoides*. GAMs are a flexible class of statistical predictive models which allow establishing relationships between a set of predictors, in our case *I. elongata* biomass, and a dependent variable. We used smoothing splines to represent the (possibly) non-linear effect of predictors. The maximum degree of smoothing allowed was 6, to avoid unrealistic patterns in the explanatory variables and to reduce overfitting (Wood, 2006). The dependent variable was modelled using a Gaussian distribution function with logarithmic link. We built a GAM for each dependent variable and selected those models yielding a statistically significant ($P < 0.1$) smoothing term. We computed the GAMs with the statistical programming environment R using the library *mgcv* (Wood, 2006).

RESULTS

Isidella elongata colonies were collected from 418–1656 m depth in the study area (Figure 1). The abundance of *I. elongata* was not related to depth (Spearman's correlation test $r = -0.092$, $P = 0.667$). The mean biomass of *I. elongata* was 97.63 ± 73.83 kg/km², with a maximum of 28 kg (1292 kg/km²) in a single haul at 626 m depth. The faunal assemblage recovered from trawl hauls containing *I. elongata* remains comprised 54 species of decapod crustaceans, 61 species of fish and 118 taxa of other invertebrates; the most characteristic taxa are shown in Table 1 (cf. Péres, 1967; Laubier & Emig, 1993).

Table 1. List of representative species recovered from trawl hauls containing the gorgonacean coral *Isidella elongata*. Species typical of the *I. elongata* facies (cf. Pérès, 1967; Emig & Laubier 1993) are marked *. Species whose typical distribution is shallower than this facies are marked – and deeper than this facies are marked + (Cartes *et al.*, 2009, and references therein).

Other invertebrates	Decapod crustaceans	Fish
<i>Abra longicallus</i> *	+ <i>Acantheephyra eximia</i>	+ <i>Alepocephalus rostratus</i>
<i>Alloteuthis media</i> *	+ <i>Acantheephyra pelagica</i>	– <i>Antonogadus megalokynodon</i>
– <i>Antedon mediterranea</i>	– <i>Alpheus glaber</i>	– <i>Argyropelecus hemigymnus</i>
– <i>Aporrhais serresianus</i>	\$ <i>Anamathia rissoana</i> *	– <i>Arnoglossus laterna</i>
<i>Bathypolypus sponsalis</i> *	<i>Aristaeomorpha foliacea</i> *	<i>Benthocometes robustus</i> *
<i>Brissopsis lyrifera</i> *	<i>Aristeus antennatus</i> *	– <i>Benthoosema glaciale</i>
<i>Natatolana borealis</i> *	<i>Calocaris macandreae</i> *	– <i>Boops boops</i>
<i>Dendrophyllum cristagalli</i> *	– <i>Chlorotocus crassicornis</i>	– <i>Callionymus maculatus</i>
<i>Crassidaria thyrrena</i> *	– <i>Dardanus arrosor</i>	– <i>Capros aper</i>
– <i>Eledone cirrhosa</i>	<i>Dorhynchus thomsoni</i> *	+ <i>Cataetyx alleni</i>
– <i>Funiculina quadrangularis</i>	+ <i>Gennadas elegans</i>	<i>Chauliodus sloani</i> *
<i>Gryphus vitreus</i> *	<i>Geryon longipes</i> *	<i>Chlorophthalmus agassizi</i> *
– <i>Heteroteuthis dispar</i>	– <i>Goneplax rhomboides</i>	– <i>Coelorhynchus coelorhynchus</i>
<i>Histioteuthis bonnellii</i> *	– <i>Macropipus tuberculatus</i>	– <i>Conger conger</i>
<i>Histioteuthis reversa</i> *	– <i>Macropodia longipes</i>	<i>Cyclothone braueri</i> *
+ <i>Hyalinema thomsoni</i> *	– <i>Medorippe lanata</i>	<i>Cyclothone pygmaea</i> *
– <i>Lunatia pulchella</i> *	– <i>Monodaeus couchii</i>	– <i>Dalatis licha</i>
<i>Meganyctiphanes norvegica</i> *	– <i>Munida intermedia</i>	– <i>Epigonus denticulatus</i>
+ <i>Mesothuria intestinalis</i> *	– <i>Munida iris</i>	– <i>Epigonus telescopus</i>
<i>Molpadia musculus</i> *	<i>Munida tenuimana</i> *	<i>Etmopterus spinax</i> *
<i>Neorossia carali</i> sp.*	– <i>Nephrops norvegicus</i>	– <i>Gadiculus argenteus</i>
+ <i>Polymastia tissieri</i> spp.*	<i>Pagurus alatus</i> *	<i>Galeus melastomus</i> *
– <i>Rissoides pallidus</i>	– <i>Pagurus excavatus</i>	– <i>Glossanodon leioglossus</i>
– <i>Rossia macrosoma</i>	<i>Pandalina profunda</i> *	<i>Helicolenus dactylopterus</i> *
+ <i>Ypsilothuria bilineata</i>	– <i>Plesionika narval</i>	<i>Hoplostethus mediterraneus</i> *
<i>Todarodes sagittatus</i> *	– <i>Parapeneus longirostris</i>	<i>Hymenocephalus italicus</i> *
	<i>Paromola cuvieri</i> *	<i>Lampanyctus crocodilus</i> *
	<i>Pasiphaea multidentata</i> *	+ <i>Lepidion lepidion</i>
	– <i>Pasiphaea sivado</i>	– <i>Lepidopus caudatus</i>
	– <i>Philocheras echinulatus</i>	<i>Lepidorhombus boscii</i> *
	<i>Plesionika acanthonotus</i> *	– <i>Lesueurigobius friesii</i>
	– <i>Plesionika antgai</i>	– <i>Lophius budegassa</i>
	– <i>Plesionika edwardsi</i>	– <i>Macrorhamphosus scolopax</i>
	– <i>Plesionika gigliolii</i>	– <i>Maurolucus muelleri</i>
	– <i>Plesionika heterocarpus</i>	– <i>Merluccius merluccius</i>
	<i>Plesionika martia</i> *	– <i>Micromesistius poutassou</i>
	<i>Polycheles typhlops</i> *	<i>Molva dipterygia</i> *
	– <i>Pontocaris lacazei</i>	– <i>Molva molva</i>
	<i>Pontophilus norvegicus</i> *	+ <i>Mora moro</i>
	– <i>Pontophilus spinosus</i>	– <i>Mullus surmuletus</i>
	– <i>Processa canaliculata</i>	<i>Nemichthys scolopaceus</i> *
	– <i>Processa nouveli</i>	+ <i>Nettastoma melanurum</i>
	<i>Richardina fredericii</i> *	<i>Nezumia aequalis</i> *
	– <i>Sergestes arcticus</i>	<i>Notacanthus bonapartei</i> *
	– <i>Sergestes corniculum</i>	<i>Notolepis rissoi</i> *
	– <i>Sergestes henseni</i>	<i>Paraliparis</i> sp.*
	<i>Sergia robusta</i> *	– <i>Peristedion cataphractum</i>
	– <i>Solenocera membranacea</i>	<i>Phycis blennoides</i> *
	+ <i>Stereomastis sculpita</i>	– <i>Raja asterias</i>
		– <i>Scyliorhinus canicula</i>
		<i>Stomias boa</i> *
		<i>Symphurus ligulatus</i> *
		– <i>Symphurus nigrescens</i>
		– <i>Synchiropus phaeton</i>
		– <i>Trachurus picturatus</i>
		– <i>Trachurus trachurus</i>
		<i>Trachyrhynchus trachyrhynchus</i> *
		– <i>Trigla lyra</i>
		– <i>Trisopterus minutus</i>
		– <i>Zeus faber</i>

\$, only 5 individuals of *A. rissoana* were recovered across the 4 surveys and they were captured in the haul with the largest catch of *I. elongata* (28 kg at 626 m depth; cf. Mura *et al.*, 2005).

Table 2. Summary of the non-parametric regression analysis (generalized additive models) between community indicators (species richness, abundance and biomass) or commercial fishery species and *Isidella elongata* abundance. Regression models were determined to be significant when the smoothing term was significant at the level $P < 0.1$ based on the approximate F statistic (Wood, 2006).

Dependent	df (smooth term)	F statistic	P	% deviance explained
Species richness—invertebrates	4.670	3.732	0.0243	62.70
Species richness—crustaceans	1.576	3.618	0.0485	33.50
Species richness—fish	1.000	0.362	0.6410	3.10
Abundance—crustaceans	1.695	9.214	0.0017	56.50
Biomass—crustaceans	3.494	3.412	0.0394	53.90
Mean size—crustaceans	1.665	0.608	0.5690	12.20
Abundance—fish	1.000	0.026	0.9450	0.23
Biomass—fish	1.250	0.372	0.6670	5.25
Mean size—fish	1.000	0.021	0.9520	0.23
Abundance— <i>Aristeus antennatus</i>	1.000	1.405	0.2530	8.07
Biomass— <i>Aristeus antennatus</i>	5.322	2.980	0.0474	70.20
Mean size— <i>Aristeus antennatus</i>	1.708	9.367	0.0021	60.20
Abundance— <i>Geryon longipes</i>	2.009	2.332	0.1400	41.60
Biomass— <i>Geryon longipes</i>	1.784	1.163	0.3620	28.10
Mean size— <i>Geryon longipes</i>	1.000	0.001	0.9960	0.01
Abundance— <i>Plesionika martia</i>	1.000	10.610	0.0076	66.60
Biomass— <i>Plesionika martia</i>	1.831	7.447	0.0159	72.00
Mean size— <i>Plesionika martia</i>	3.197	2.969	0.1180	69.30
Abundance— <i>Phycis blennoides</i>	6.552	31.97	<0.0001	97.10
Biomass— <i>Phycis blennoides</i>	1.000	0.453	0.5130	3.37
Mean size— <i>Phycis blennoides</i>	4.633	2.585	0.0983	60.80

Table 2 shows the results of the non-parametric regression between community indicators and *I. elongata* abundance. Only regression models with a significant smooth term were considered and they are shown in Figure 2. The relationship between *I. elongata* abundance and non-significant community indicators is presented with simple scatterplots (Figure 2). Species richness of invertebrates was higher at intermediate densities of *I. elongata*, with maximum species richness at around 1 kg km^{-2} . Crustacean species richness, abundance and biomass were significantly higher at higher densities of *I. elongata*, while for mean size no effect of the coral was determined. Fish species richness, abundance, biomass or mean size were not significantly related to *I. elongata* density.

The non-parametric regression analysis of fisheries target species (Figure 3; Table 2) shows that biomass and mean size of the red shrimp *Aristeus antennatus* are significantly higher at higher densities of *I. elongata*. The crab *Geryon longipes* was not significantly affected by *I. elongata* biomass, but the crab was mostly present at coral densities below 1 kg km^{-2} . Both abundance and biomass of the shrimp *Plesionika martia* were positively correlated with *I. elongata*, but not mean size of this shrimp. In the case of the greater forkbeard *Phycis blennoides* a non-monotonic significant response was determined for abundance and mean size, with maximum abundance of the fish at intermediate biomass of *I. elongata* ($5\text{--}150 \text{ kg km}^{-2}$) and maximum fish size at relatively low biomass of the coral ($0.1\text{--}1 \text{ kg km}^{-2}$).

DISCUSSION

The deep-water coral *I. elongata* was recovered from 418–1656 m depth in 20 of 189 trawl hauls from 4 intense trawl sampling surveys between 1985 and 2008. This deep-water coral is increasingly rare in the Mediterranean due to intense fishing pressure from trawlers targeting the red shrimp at

continental slope depths (mainly between 400 and 800 m), who detach the coral from the soft bottom or destroy its branches. Our results show that higher densities of coral support higher crustacean species richness, abundance and biomass and are significantly related to overall invertebrate richness. Some indicators for species of commercial interest are also significantly related to higher density of the coral. Trawling, by destroying coral colonies, may decrease crustacean species richness, abundance and the biomass of some commercial species (*A. antennatus* and *Plesionika martia*).

Similar findings by Husebø *et al.* (2002) report that fish abundance was higher and fish size was larger in *Lophelia* reefs in Norwegian waters, although in our study the main living resource (*Aristeus antennatus*) of mid-slope depths in the north-western Mediterranean was not more abundant, but only showed higher biomass and mean size; confirming the observations by Pérès (1967) that this species is characteristically associated with *I. elongata* facies, at least as adult. By contrast, we could not confirm the nursery habitat provided by deep-water reefs of *Lophelia pertusa* for commercial fish as in the North Atlantic (Fosså *et al.*, 2002), at least for the target species of the trawl fishery in the area. In the Mediterranean, the shelf break habitat characterized by the crinoid *Leptometra phalangium* has also been shown to support increased abundances of recruits and juveniles of important commercial species, such as *Merluccius merluccius*, *Phycis blennoides* or *Parapenaeus longirostris* (Colloca *et al.*, 2004) and a similar role for white coral reefs in the central-eastern Mediterranean has recently been shown (D'Onghia *et al.*, 2010).

Analyses of possible causes explaining the positive effect of *I. elongata* biomass on decapod crustaceans are necessarily speculative because of a lack of specific studies. From a trophic point of view, *Aristeus antennatus* has the most diversified diet ($H' = 5.3$; Cartes, 1994) among deep-Mediterranean species. Trophic studies show that most infaunal prey ingested by

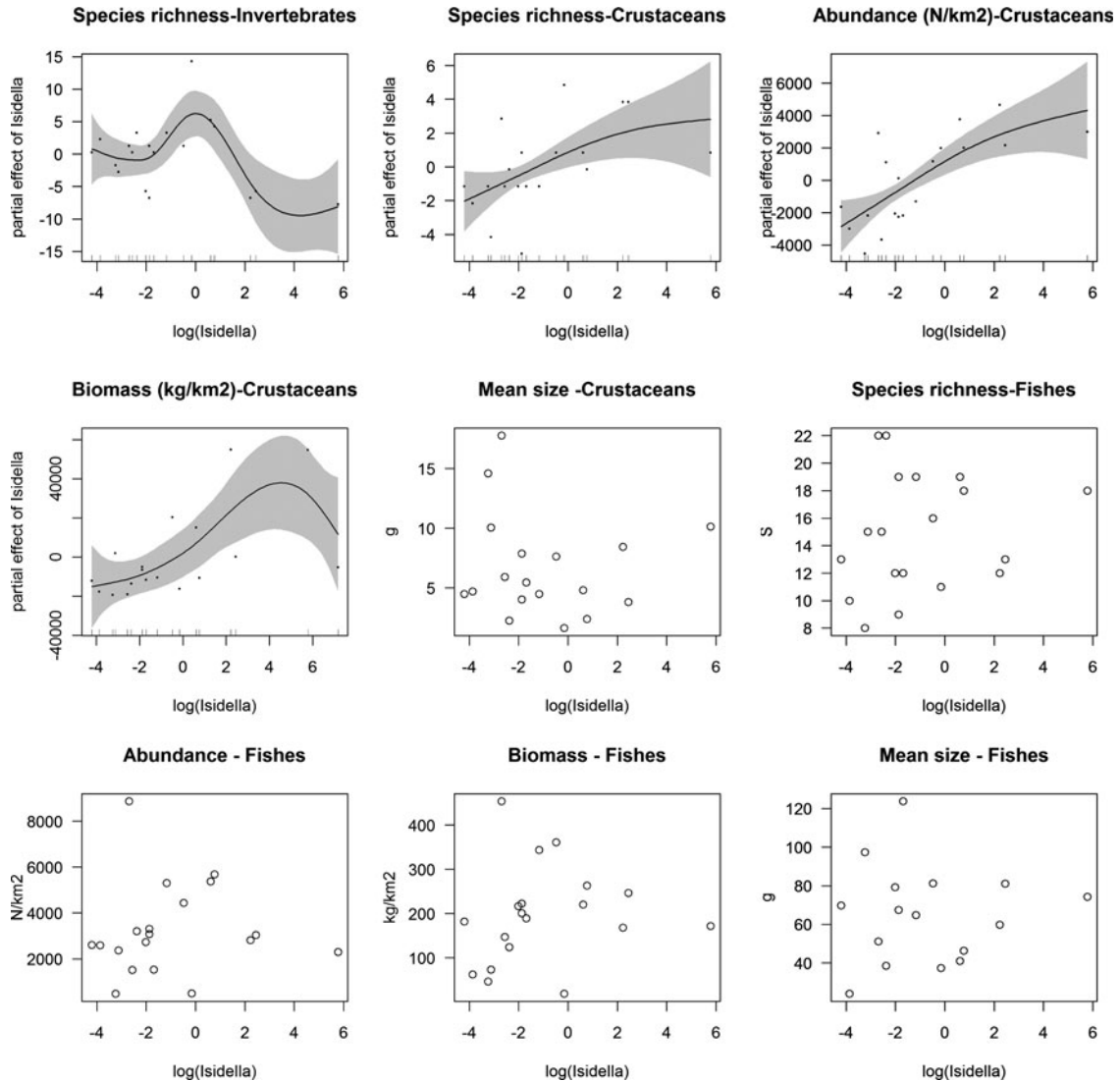


Fig. 2. Results of the non-parametric regression analysis (generalized additive models) between community indicators (species richness, abundance and biomass) and *Isidella elongata* biomass. When the regression model was not significant a simple scatterplot is shown.

A. antennatus in non-trawled bottoms (below 1000 m depth) are captured by rooting in mud (e.g. polychaetes and bivalves: Cartes, 1994). This species of broad trophic spectrum may act as an opportunistic species, feeding on the rich invertebrate communities associated with *I. elongata* meadows. The possible alteration of trophic webs by trawling on *Isidella* facies must have two different effects: (i) a short-scale, immediate effect by increasing prey availability after damaging and habitat alteration of benthos; and (ii) a longer scale effect on benthos production. The effects of chronic disturbance on production are a decrease in P and a parallel increase in P/B (Jennings *et al.*, 2001) basically by elimination of large sizes.

The disturbance created by trawling on continental-slope communities decreases community structure (species richness) and damages the habitat of invertebrates and some commercial decapod and fish species (Jennings & Kaiser, 1998). *Isidella elongata*, together with other suspension feeders (*Desmophyllum cristagalli* and *Gryphus vitreus*), is mainly distributed in the Balearic Basin over the middle and lower continental slope, between two depositional areas of sediment and particulate organic matter occupied by deposit feeders

(holothurians and *Brissopsis lyrifera*: Cartes *et al.*, 2009). Studies on trophic webs in the area suggest the belt occupied by *I. elongata* is rich in near-bottom zooplankton (Cartes *et al.*, 2009), the main food source for deep-corals (Sherwood *et al.*, 2005). In addition to the direct impact or damage created by the mechanical action of trawling, deep-water coral reefs are also negatively impacted by the resuspension of bottom sediments which clogs the filter-feeding mechanisms of suspension feeder species (Rogers, 1999; Fossà *et al.*, 2002) probably altering zooplankton availability to *Isidella* polyps. Palanques *et al.* (2005) detected resuspension of sediments due to trawling even downstream from the main fishing grounds, below 1000 m depth.

The very slow growth rates of deep-water corals (Andrews *et al.*, 2002; Fossà *et al.*, 2002; Krieger & Wing, 2002) make problematic the recovery of these habitats from trawling in the short and medium term. In addition to trawling, the threat of solid refuse dumping to *I. elongata* facies was already pointed out by Relini Orsi (1974). Other human activities, such as mineral extraction (Grassle, 1991; Thiel, 2003) may be highly detrimental to deep-sea ecosystems and

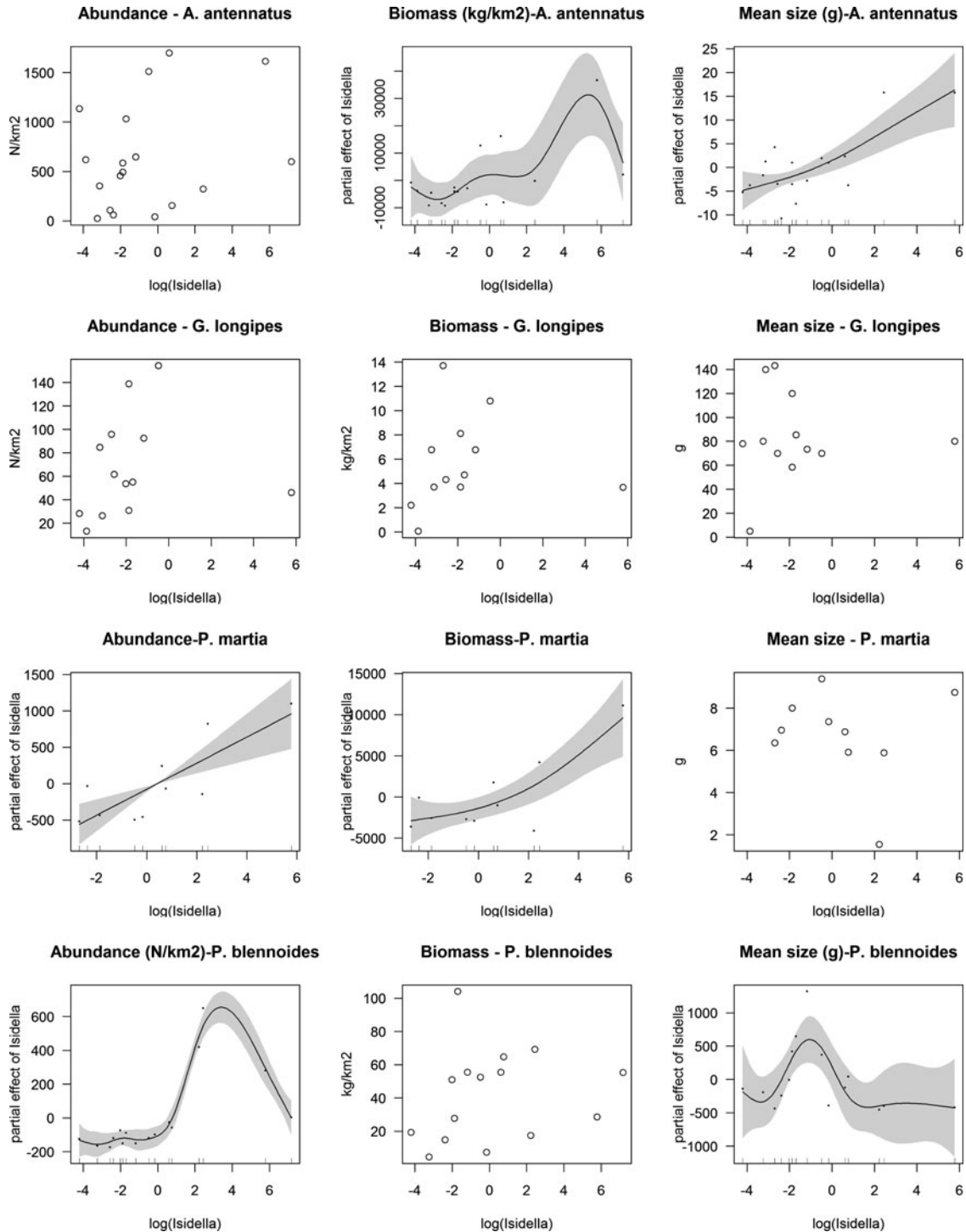


Fig. 3. Results of the non-parametric regression analysis (generalized additive models) between commercial fishery target species (abundance, biomass and mean size) and *Isidella elongata* biomass. When the regression model was not significant a simple scatterplot is shown.

the services provided by these to humans (e.g. fisheries: Roberts, 2002). Sustainable fisheries require viable stock populations but also appropriate habitat. Deep-water corals provide essential habitat, either as reefs (scleractinians) or stands (gorgonaceans) necessary for fish to survive (feeding, protection or reproduction places) and the impact of human activities on deep-water, fragile ecosystems must be carefully monitored and assessed.

ACKNOWLEDGEMENTS

We thank participants in the cruises BATIMAR, ZONAP, GEODELTA and BIOMARE for their assistance during fieldwork. Funding for the project BIOMARE (CTM-2006-13508-Co2/MAR) was provided by the Spanish National Research Programme. Current research by the authors on deep-water habitats is funded by project

ANTROMARE (CTM-2009-12214-C02/MAR) of the Spanish National Research Programme.

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Correspondence should be addressed to:

F. Maynou
 Institut de Ciències del Mar (CSIC)
 Psg. Marítim de la Barceloneta 37-49, 08003 – Barcelona, Spain
 email: maynouf@icm.csic.es