Hydrobiologia (2011) 670:67–85
DOI 10.1007/s10750-011-0670-z

Assessment of the deep water trawl fishery off the Balearic Islands (western Mediterranean): from single to multi-species approach

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Published online: 25 March 2011

Abstract The bottom trawl fishery developed on the slope off Balearic Islands (western Mediterranean) has been analysed from different sources of information: (i) data obtained during experimental bottom trawl surveys developed annually since 2001; (ii) daily sale bills from the bottom trawl fleet, available since 2000. Considering both hydrographical and geomorphologic conditions, the study area was divided in four geographical sectors. Multivariate techniques were applied to identify assemblages and their main species, and to investigate the influence of environmental variables in the slope communities. Fishery-independent and fishery-dependent indicators were calculated, both at specific and community level, for the assemblages identified. In all cases, they were summarised using the Traffic Light approach. Three assemblages have been identified in the slope trawl fishing grounds off the Balearic Islands: (1) the almost unexploited shelf break, where teleosts predominate; (2) the upper slope, where teleosts still predominate but crustaceans are also very important (with *Nephrops norvegicus* as target species); (3) and the middle slope, where crustaceans predominate (with *Aristeus antennatus* as target species). Depth was the main factor affecting the species composition of the assemblages, although other factors such as area, year and effort level also affect. Indicators estimated from both sets of data suggested an improvement in the state of *N. norvegicus*, although the results suggest the influence of other factors than fishing impact in the state of this resource. For *A. antennatus*, marked differences have been found depending on the data source. In the upper slope, indicators suggested an improvement in the state of this assemblage, which can be related to a decreasing trend found in the fishing effort exerted in this depth range. Indicators from the middle slope showed differences for both sets of data. The characteristics of both data sources and of the species analysed are discussed as responsible of these differences.

Keywords *Nephrops norvegicus* · *Aristeus antennatus* · Assessment · Community · Ecosystem approach · Indicators · Traffic Lights

Guest editors: Graham J. Pierce, Vasilis D. Valavanis, M. Begoña Santos & Julio M. Portela / Marine Ecosystems and Sustainability

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Introduction

Mediterranean bottom trawl fisheries are multispecies as they are targeting more than 100 demersal species of fish, crustaceans and molluscs, with an important commercial value and abundance (Caddy, 1993; Lleonart & Maynou, 2003). In spite of that mono-specific approaches are usually the rule in assessments (e.g. Farrugio et al., 1993; Lleonart & Maynou, 2003). In recent years, there has been a progressive change from the traditional approach of fishery assessment to a new ecosystem approach (Browman & Stergiou, 2004; Pikitch et al., 2004). This new approach is particularly important in the multi-species Mediterranean fishery, as the calculations for a single species are of limited value for management in this type of fisheries (Caddy, 1993).

Within the ecosystem-based approach, there is an increasing need for measuring the impact of fishing on ecosystems and, as a consequence, many indicators targeting various components of ecosystems have been developed and discussed (e.g. Trenkel & Rochet, 2003; Nicholson & Jennings, 2004). One of the ways of using indicators is examining whether the indicator is currently changing (Rochet & Trenkel, 2003). However, the complexity of exploited ecosystems forces to examine multiple indicators to accumulate evidence, raising the question of how to summarise them. One of the ways is the Traffic Light (TL) method. This approach was firstly proposed as a type of precautionary management framework suitable for use in fishery assessment in data-poor situations (Caddy, 1999, 2002), but it can be used to assess the status of all stocks whether rich or poor in data (Halliday et al., 2001). The TL displays time series in such a way that helps to perceive likely transitions of indicators and relationships between variables visually (Caddy et al., 2005). This methodology has been applied for single- and multi-species assessments both in the Atlantic and the Mediterranean (Caddy et al., 2005; DFO, 2005; Ceriola et al., 2007, 2008) and appears to be more precautionary than traditional stock assessment methods (Koeller et al., 2000).

Over the last times, the methods available to be used in stock assessment models have changed from those using only catch, catch-at-age and survey or CPUE data to methods that use every source of data available in a totally integrated framework (Hilborn, 2003). In this sense, TL provides a way of bringing a variety of monitoring results, results from traditional stock assessment models and methods, anecdotal observations and political/economic considerations into management decisions (Koeller et al., 2000). One of the main shortcomings in Mediterranean fishery assessments, which is related to their diversity and complexity, is the lack of suitable data because in spite of the existence of fairly reliable historical data series of landings, data on effort are almost absent (Lleonart & Maynou, 2003). In this sense, experimental bottom trawl surveys are very useful, not only because they avoid factors such as fisheries behaviour which could bias estimates on commercial data, but also because they can provide information from the entire epibenthic community. In this sense, fishery-independent data allow the study of single species (e.g. Abella et al., 1999; Lombarte et al., 2000; Tserpes & Peristeraki, 2002), taxonomic groups (Abelló et al., 2002a; Massutí & Moranta, 2003) and faunal assemblages (Moranta et al., 1998; Massutí & Reñones, 2005; Dimech et al., 2008), constituting an appropriate tool for an ecosystem-based fisheries management.

In the Balearic Islands, assessments of some of the main species exploited by the bottom trawl fishery have been made based on population dynamics (Oliver, 1993; García-Rodríguez & Esteban, 1999), production models (Carbonell & Azevedo, 2003) and regression analysis (Alemany & Alvárez, 2003), all of them have considered the single species as the basic unit of the analysis. Multi-species studies have been performed considering fish and cephalopod assemblages separately (Massutí et al., 1996; Moranta et al., 2000; Quetglas et al., 2000), as well as the entire megafaunal demersal communities (Massutí & Reñones, 2005; Moranta et al., 2008; Ordines & Massutí, 2009).

The aim of this article is to assess the deep water trawl fishery resources off the Balearic Islands from single to multi-species approach. This article has three main objectives: (i) to identify and characterise the species assemblages in the deep water trawl fishing grounds off the Balearic Islands; (ii) to analyse the spatio-temporal trends in abundance and biomass from different taxonomic groups, including the influence of environmental conditions and (iii) to estimate ecological indicators (both at single- and multi-species level) to assess the impact of fishing on these communities.

Materials and methods

Study area

The Balearic Islands delimit two sub-basins in the western Mediterranean, the Balearic sub-basin (BsB) in the north and the Algerian sub-basin (AsB) in the south (Fig. 1). The shelf in the Balearic archipelago is narrow and steep on the northern side, and wider and gentler in the south. Terrigenous-muddy sediments are not abundant due to the absence of river discharges. Sandy-muddy and detrital sediments occur at the shelf-slope break, whereas muddy bottoms of biogenic origin dominate the deeper areas (Acosta et al., 2002). The hydrographic conditions of the Islands have been studied widely, with the Balearic channels described as important passages for the exchange between the cooler, more saline waters of the BsB and the warmer, fresher waters of the AsB (Pinot et al., 2002). The temporal variability in hydrodynamic conditions of the area is mainly conditioned by the Northern Current (NC), which carries waters formed during winter in the Gulf of Lions southwards along the continental slope, and reaches the channel between the Iberian coast and the Islands (BsB) (Pinot et al., 2002; López-Jurado et al., 2008; Monserrat et al., 2008).

The demersal communities of the Balearic Island fishing grounds are exploited by a relatively small bottom trawl fleet (around 50 boats), which performs daily fishing trips. Different levels of effort have been detected around the islands, showing the higher levels in the fishing grounds sited in the south and west of Mallorca (Moranta et al., 2008; Serrano et al., 2008). Four different fishing tactics are developed by this fleet, associated with the shallow and deep continental shelf, and the upper and middle continental slope (Guijarro & Massutí, 2006; Ordines et al., 2006). They are mainly targeting striped red mullet (*Mullus surmuletus*), European hake (*Merluccius merluccius*), Norway lobster (*Nephrops norvegicus*) and red shrimp (*Aristeus antennatus*), respectively. Taking into account both environmental and fishing effort variability, four different areas have been considered during this study (Fig. 1; Table 1).

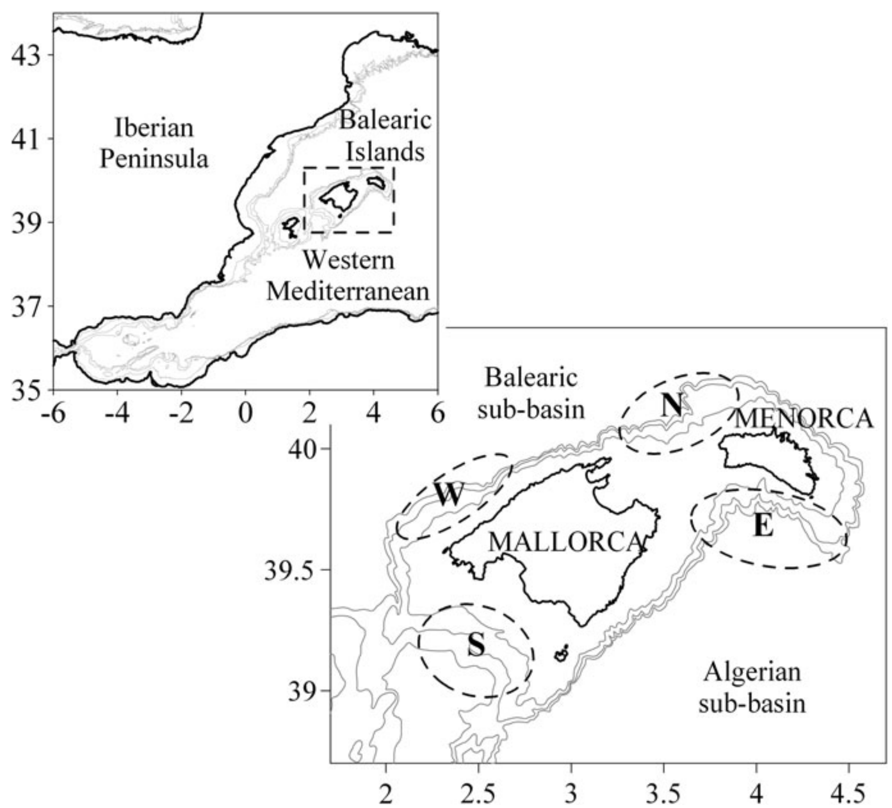

Fig. 1 Map of the study area, showing the areas considered for the analysis of data obtained during the experimental bottom trawl surveys, and the 200, 600 and 800 isobaths

Table 1 Summary of the environmental and fishery characteristics of each of the areas of the Balearic Islands analysed during the study, based on previous studies carried out in the study area (Pinot et al., 1995, 2002; Acosta et al., 2002, 2004; López-Jurado et al., 2008; Monserrat et al., 2008; Serrano et al., 2008)

Area	North	West	South	East
Sub-basin	Balearic	Balearic	Algerian	Algerian
Hydrology	Balearic front	Balearic front	No Balearic front	No Balearic front
	Cooler and more saline waters	Cooler and more saline waters	Warmer and fresher waters	Warmer and fresher waters
Bottom	Steep	Steep	Gentle, small canyons, submarine mountain	Steep, one big submarine canyon
Fishing effort	Low	Medium–High	Medium–High	Low

For fishing effort, low: <500 days/year; medium: 500–1000 days/year; high: >1000 days/year

Data source

Two different sources of data were used. Firstly, fishery-independent data was obtained from experimental bottom trawl surveys carried out in the Balearic Islands between 2001 and 2008, during late spring and early summer, following the international MEDITS bottom trawl surveys protocol (Bertrand et al., 2002). For an initial number of 452 stations sampled, 153 were considered for this study (15–20 stations by year), which correspond to those carried out in the slope (between 200 and 800 m depth). The number of stations analysed by area were 44, 35, 43 and 31 for the northern, western, southern and eastern areas, respectively. Information obtained was related to the total catch (in biomass and abundance) by species, length frequency distributions of all fish, and commercial crustaceans and cephalopods, and biological sampling (individual length, weight, sex and maturity) of the main commercial species. Secondly, fishery data was obtained from the landings of the bottom trawl fleet which operates in the island of Mallorca between 2000 and 2008. This information consisted in the biomass landed by species or commercial categories. Each of the 60,847 daily sale bills was assigned to one or more fishing tactics following the methodology described by Palmer et al. (2009) and only those trips carried out in the upper and middle slope (41,729) were used.

Community analysis

Different multivariate techniques were used in order to analyse biomass and abundance indices by station, obtained from the surveys, expressed in terms of weight (g) and number per km^2. Only species with a frequency of occurrence (FO) larger than 15% in all surveys were included in the analysis in order to reduce the variability in the species matrix due to the presence of a lot of zero values. As a first step, cluster analysis and multidimensional scaling were applied after square root transformation to identify assemblages. The Bray-Curtis similarity index was chosen as the similarity coefficient and Group Average was utilised as the clustering algorithm (Clarke & Warwick, 1994). Similarity Percentage Analysis (SIMPER) was applied to identify the species that mostly contribute to the differences among the detected station-groups (Clarke, 1993). In addition, supervised machine-learning approaches (Mitchel, 1997), and in particular the decision-tree construction method as implemented by the C4.5 algorithm (Quinlan, 1993), were employed as an alternative method to identify the power of the examined species (attributes) in classifying the stations into the pre-defined depth classes. In order to assess the power of the predicted classification scheme, the analysis was firstly applied to the 2001–2005 data set (learning data), and the decision trees built were used to predict the classification of the 2006–2008 data (test data) into the assemblages previously detected.

Redundancy Analysis (RDA, ter Braak & Smilauer, 2002) was also applied to link the species composition matrix (biomass and biomass) directly with the environmental matrix. Environmental information available was depth, hydrography (temperature, salinity and flow velocity near the bottom) obtained from a model and phytoplankton pigment concentration (ppc, mg Chl a/m^3), obtained from Kempler (2009), as indicator of the availability of trophic resources at the lowest levels of the trophic chain (Cartes et al., 2004). Data from different periods, simultaneously and before 1, 2, 3 and 4 months of the sampling, were considered. Fishing effort was also included in the model. Three levels of effort were considered: low (<500 days/year), medium (500–1000 days/year) and high (>1000 days/year). For each of the stations, an effort level was assigned taking into account the fishing tactic, the number of daily fishing trips and the nearest port. The variables included in the model were depth, area, year, effort, temperature, current velocity, simultaneous ppc and ppc 3 and months before sampling. Generalized Additive Models (GAM; Hastie & Tibshirani, 1990) were used to relate abundance of different taxonomic groups with environmental variables. The taxonomic groups considered were elasmobranchs, teleosts, crustaceans, molluscs and others. The variables included in the model were the same than for the RDA.

Fishery-independent indicators

At population level (i.e. *N. norvegicus* and *A. antennatus*), indicators used were FO, abundance (A, n/km^2), biomass (B, g/km^2), centre of gravity (COG, Daget, 1976), size-based indicators and condition index (Kn; Le Cren, 1951). FO, A and B were computed both for total population and for recruits. The COG model allows calculating and locating with precision the centre of species distributions by means of a descriptor (in this case, depth). It is determined as follows:

$$\mathrm{COG} = (x_1 + 2x_2 + 3x_3 + \cdots + nx_n)/\Sigma(x_i),$$

where x_i represents the calculated mean abundance values of the species x present in the stratum i (before analysis the sampled depth was divided into strata of 100 m). Size-based indicators calculated were mean (ML) and mean maximum length (MML) and mean (MM) and mean maximum body mass (MMBM). MML and MMBM were computed averaging the maximum length/body mass of each species in each haul. The individual weight of each specimen was calculated from bibliographic length–weight relationships (Merella et al., 1997; Quetglas et al., 1998a, b; Company & Sardà, 2000; Papaconstantinou & Kapiris, 2003; Morey et al., 2003; Mendes et al., 2004) as well as own data obtained during these surveys and other surveys carried out in the same area (Moranta et al., 2008). Kn was calculated as observed weight over expected weight, estimated from a length–weight relationship calculated considering all biological data available, by sex.

At the community level, assessment was performed using density, diversity and size-based indicators. Density indicators were abundance (n/km^2), biomass (g/km^2) and percentage of non-commercial species (both in abundance and biomass). Diversity indicators were total number of species (S), species richness (Margalef, $d = (S - 1)/\log(N)$, where N is the total number of individuals), Pielou's evenness ($J' = H'/\log(S)$), Shannon–Wiener index ($H' = -\mathrm{SUM}(P_i * \log_2(P_i))$, where P_i is the proportion of each species in each sample) and ABC plots (K-dominance curves, Warwick, 1986; Clarke, 1990). For the latter, those species only reported in a single haul or in a single survey were removed. As the results of ABC plots depend on the species included in the analysis (Jouffre & Inejih, 2005), a second analysis was performed including only those species which have appeared in all surveys. Size-based indicators were biomass, abundance and diversity spectra, and the above-described MML, ML, MMBW and MBW.

Normalised biomass size spectra (Jennings et al., 2002) were computed by dividing the biomass in a given body-mass class interval by the width of that class interval (in antilog dimensions). The relationship between body mass (as $\log_2$ classes) and total normalised biomass ($\log_2$ transformed) was described using least squared linear regressions, considering only the body mass class in which the biomass starts to decline. Size spectra (Bianchi et al., 2000) were constructed for each survey by plotting the natural logarithm of the total number of individuals caught by 5-cm length class against the natural logarithm of the middle of each length class. Diversity spectra (Gislason & Rice, 1998) were constructed by plotting the Shannon–Wiener index (calculated for each 5-cm length class) against the mid-length of each length group. For these three metrics, the slope of the spectrum for each year or area was used as an indicator of changes in the exploitation rate (Bianchi et al., 2000). The slope decreases when decreases fishing mortality (Hall et al., 2006), so it can be considered a good measure of fishing impacts (Gislason & Rice, 1998).

Fishery-dependent indicators

At population level, density and economic indicators were computed. Density indicators were annual landings by vessel (as kg/vessel), landings per day for total fleet (as kg/day), landings per vessel and day (LPUE, as kg/day/vessel), both for total population and the small-sized commercial category (as a proxy of recruits). Economic indicators (Ceriola et al., 2008) were revenue by vessel (€/vessel), revenue by day (as €/day), revenue by vessel and day (RPUE, as €/day/vessel) and average price (as €/kg). At community level, these same indicators were computed, but without taking into account size-groups. Number of boats and number of days were also calculated.

Traffic Lights

The summary of these indicators, both fishery-dependent and independent indicators and both at population and community level, was performed using TL (Caddy, 1999, 2002; Koeller et al., 2000). The TL is a system of red, yellow and green lights which categorise multiple indicators of the state of a fishery and ecosystem, considering red as bad, yellow as intermediate and green as good. A number of options are available for establishing boundaries for TL, like Limit Reference Points, a percentage of the average value or using the 33rd and 66th percentiles (Halliday et al., 2001). This last option was used in this work, adapting the rules depending of the expected effect of increasing fishing pressure in each indicator. Although TL has been usually employed for evaluating temporal variation of indicators in assessment (DFO, 2005; Ceriola et al., 2007, 2008), in this work, both spatial and temporal trends were tested using this method. Thus, a mean value for each of the indicators has been computed by year or area and a different colour was assigned if this value was under the 33rd percentile (red, bad state), between the 33rd and 66th percentile (yellow, intermediate state) or over the 66th percentile (green, good state). For those indicators that we expect to increase with high fishing pressure (like effort indicators themselves or percentage of non-commercial species), the rules were the opposite. As a summary, a single TL was created for fishery-independent and fishery-dependent data, assigning the colour of the most abundant one for each year or area.

Results

Community description and influence of environmental variables

Total catch during the 8 years of experimental bottom trawl surveys in the fishing grounds of the slope of the Balearic Islands was 11,391 kg and 725,817 individuals, of a total of 363 species (or families when it was not possible to arrive at species level) corresponding to 108 teleosts, 19 elasmobranchs, 75 crustaceans, 46 molluscs, 27 echinoderms and 94 belonging to other groups.

Cluster and MDS results showed three different groups related to depth (Fig. 2), corresponding to those hauls carried out between 200 and 299 m depth (SB, shelf break), 300 and 499 m depth (US, upper slope) and 500 and 800 m depth (MS, middle slope). The results of the SIMPER analysis (Table 2) showed high values of average dissimilarity between groups, larger than 90%, and confirmed the presence of these well-defined groups. The species that characterise the SB were mostly teleosts (like *Capros aper*, *M. merluccius* and *Micromesistius poutassou*) and the elasmobranch *Scyliorhinus canicula*. The most important species in the US were also teleosts, crustaceans (from the genus *Plesionika*, *Parapenaeus longirostris* and *N. norvegicus*), the elasmobranch *Galeus melastomus* and the cephalopod *Sepietta oweniana*. In the MS, crustaceans were predominant (like *A. antennatus*), followed by teleosts and the elasmobranchs *G. melastomus* and *Etmopterus spinax*. Decision-tree analysis confirmed these groups, as the supervised machine-learning showed a very high level of classification (Table 3). Miss-classification was higher for the stations belonging to the shallowest group in which the number of samples was the lowest.

Full models from the RDA results were found significant ($P < 0.01$) both for biomass and abundance (Table 4). Depth was the main factor affecting the species composition, while the rest of the significant variables explained low percentages of the variance. In any of the models, the variables related to primary production were found to be significant. Deviance explained from the GAM models applied to biomass of all the groups analysed varied between 25 and 79% (Table 5). In all cases, depth and year were significant factors. For total, elasmobranchs, teleosts, molluscs

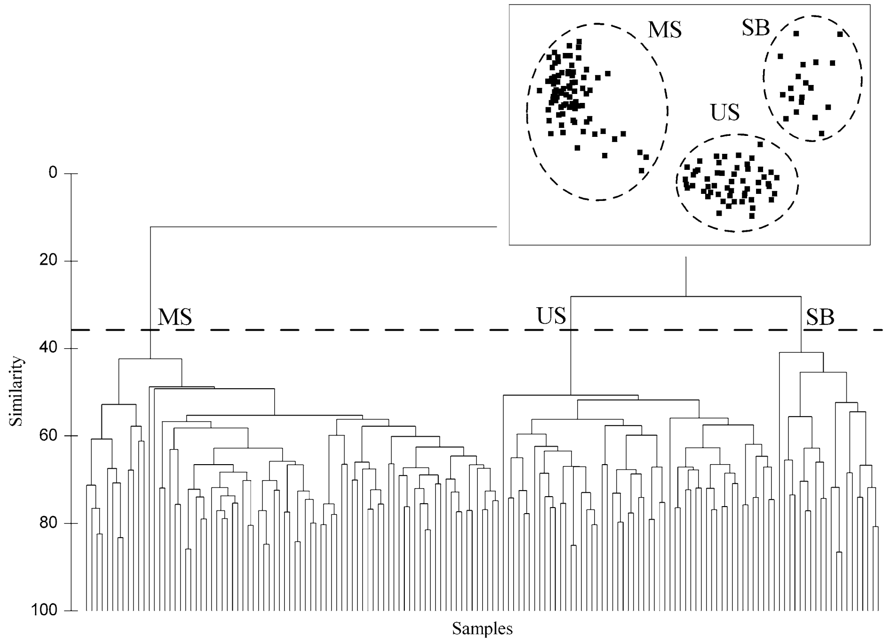

Fig. 2 Dendrogram and MDS ordination of samples made during the experimental bottom trawl surveys, showing the three different assemblages obtained from the cluster analysis: shelf break (SB, 200–299 m), upper slope (US, 300–499 m) and middle slope (MS, 500–800 m)

and others there was a non-linear decreasing trend with depth and crustaceans showed an increasing trend with depth (Fig. 3). By years, both elasmobranchs and crustaceans showed the highest values for 2002, and molluscs in 2005, although any taxonomic group showed a clear inter-annual trend. Area was a significant factor for some of the taxonomic groups as biomass showed the highest values in the north for total and teleosts and in the south for crustaceans. Fishing effort was marginally significant for elasmobranchs and crustaceans, with different trends: the highest values of biomass for elasmobranchs were found with low or medium levels of fishing effort, but for crustaceans it was higher with medium and high levels.

Fishery assessment

Traffic Light method for *N. norvegicus* showed similar results among years and areas with both set of data (Fig. 4). The highest proportion of reds was found in the first years (except for 2002 for density indicators) and of greens in the last years. Condition of both males and females did not show this trend, with the lowest values during the last year. Spatially, the highest number of greens were found in the northern and southern locations (although the northern location showed reds in the length-based indicators) and of reds in the eastern. In fact, in this location, length-based indicators could not be computed due to the low number of individuals caught. On the contrary, TL for *A. antennatus* showed very different results with both set of data (Fig. 5). Density indicators from surveys showed high numbers of reds during the last years (except for 2008). The opposite trend has been found for fleet-based indicators, with the highest numbers of reds at the beginning of the series. Condition showed differences between both sexes, with the lowest values of the series for males in the last 2 years. Spatial TL showed some differences but depending on the group of indicator. For example, in the case of fishery-independent indicators, the east showed high number of greens for density indicators but reds for size-based and condition indicators. In the case of fishery-dependent indicators, the south showed high number of reds for density indicators but of greens for economic ones. On the contrary, the west showed the highest numbers of greens in all cases.

At community level, TL for US showed similar results with both sources of data (Fig. 6). Although the summary in both cases was quite similar, without red values in the last 3 years, fishery-independent indicators showed reds, yellows and greens distributed heterogeneously along years. By contrast, number of reds was very low for the fishery-dependent indicators during the last 3 years. Spatially, fishery-independent indicators showed high number of reds

Table 2 SIMPER results for each assemblage identified from the dendogram and for the species that contributed to at least 90% of the differences between these groups: mean abundance (Av. Ab. as n/km^2), average similarity (Av. Sim.), standard deviation (SD), percentage contribution to the similarity (Contrib%), percentage contribution to the similarity accumulated (Cum.%), average dissimilarity (Av. Diss.)

Species	Tax.	Av. Ab.	Av. Sim.	Sim/SD.	Contrib%	Cum.%
Shelf break; Av. Sim. = 27.21						
Scyliorhinus canicula	EL	3545.91	9.46	0.85	34.78	34.78
Capros aper	TE	18084.62	6.32	0.65	23.24	58.02
Merluccius merluccius	TE	1714.21	3.66	0.58	13.46	71.47
Micromesistius poutassou	TE	3982.98	2.55	0.36	9.39	80.86
Synchiropus phaeton	TE	1077.83	1.55	1.05	5.68	86.54
Helicolenus dactylopterus	TE	645.19	1.35	0.76	4.96	91.50
Upper slope; Av. Sim. = 33.37						
Gadiculus argenteus	TE	13609.48	14.21	1.09	42.59	42.59
Galeus melastomus	EL	2438.46	2.18	0.70	6.53	49.13
Caelorynchus caelorhynchus	TE	1961.63	2.06	0.88	6.16	55.29
Plesionika heterocarpus	CR	4543.87	1.97	0.45	5.91	61.19
Sepietta oweniana	MO	1319.66	1.65	0.81	4.94	66.13
Chlorophtalmus agassizi	TE	2406.85	1.59	0.64	4.76	70.90
Plesionika giglioli	CR	857.83	1.50	0.61	4.51	75.40
Helicolenus dactylopterus	TE	1048.90	1.26	1.02	3.77	79.17
Phycis blennoides	TE	545.00	1.19	0.89	3.57	82.75
Micromesistius poutassou	TE	1534.96	1.16	0.63	3.47	86.21
Plesionika antigai	CR	731.23	0.59	0.62	1.77	87.99
Parapenaeus longirostris	CR	966.57	0.58	0.45	1.75	89.74
Nephrops norvegicus	CR	553.20	0.52	0.37	1.57	91.31
Middle slope; Av. Sim. = 36.17						
Aristeus antennatus	CR	2687.68	12.16	1.05	33.63	33.63
Lampanictus crocodrilus	TE	1924.95	7.80	1.12	21.57	55.19
Plesionika martia	CR	811.75	2.78	0.81	7.68	62.87
Galeus melastomus	EL	704.30	2.20	0.77	6.08	68.95
Phycis blennoides	TE	348.62	2.12	0.94	5.87	74.82
Pasiphaea multidentata	CR	554.38	2.11	0.54	5.83	80.65
Nezumia aequalis	TE	273.38	1.67	1.03	4.61	85.26
Plesionika acantonothus	CR	220.29	0.87	0.62	2.41	87.67
Sergia robusta	MO	258.48	0.80	0.46	2.22	89.89
Geryon longipes	CR	130.28	0.74	0.52	2.05	91.93

Pairwise comparisons	Av. Diss.
Shelf break vs. upper slope	89.73
Shelf break vs. middle slope	99.03
Upper slope vs. middle slope	94.39

Taxonomic group (Tax.) for each of the species is also shown (*TE* teleosts, *EL* elasmobranchs, *CR* crustaceans, *MO* molluscs)

in the south and of greens in the east and the north. For fishery-dependent indicators, number of reds was lower in the north and south. The west and south showed the highest levels of effort. TL for MS showed several differences between both sources of data, but depending on the type of indicators (Fig. 7).

Table 3 Estimated "information gain" for the 15 highest rates for the examined attributes (species) from the supervised machine-learning approach and classification success by assemblage for the training and the test data sets

Attribute (species)	Information gain
Sepietta oweniana	0.941
Aristeus antennatus	0.850
Gadiculus argenteus	0.829
Lampanictus crocodrilus	0.773
Synchiropus phaeton	0.753
Nezumia aequalis	0.751
Lepidorhombus boscii	0.722
Scyliorhinus canicula	0.692
Capros aper	0.691
Sergia robusta	0.644
Parapenaeus longirostris	0.639
Helicolenus dactylopterus	0.625
Chlorophtalmus agassizi	0.613
Trigla lyra	0.606
Geryon longipes	0.584

Class	Classification success	
	Training (%)	Test (%)
Shelf break	100	63
Upper slope	100	100
Middle slope	100	96

Density indicators from fishery-independent data showed a temporal transition from high number of greens to high number of reds. The opposite trend was found for diversity indicators. Size-based indicators did not show any clear temporal trend. In general, fishery-dependent indicators went from high number of reds to high number of greens. Spatially, results were similar between both sources of information, with the highest number of reds in the north and the lowest in the east.

Discussion

Three different assemblages have been detected in the slope off the Balearic Islands, with the bathymetric gradient as the main factor conditioning them: the shelf break (200–299 m), the upper slope (300–499 m) and the middle slope (500–800 m). The shallowest assemblage corresponds to a bathymetric zone where the fleet usually does not operate. The other two assemblages can be comparable to the fishing tactics (FT) identified in the crustacean bottom trawl fishery in the Balearic Islands, targeting the Norway lobster *N. norvegicus* and the red shrimp *A. antennatus*, in the upper and middle slope, respectively (Guijarro & Massutí, 2006; Palmer et al., 2009). These assemblages are in agreement with previous studies performed in the same area (Massutí & Reñones, 2005), where the existence of six species assemblages was described, three of them in the slope similarly to those found in this study.

Depth is generally considered as the main factor governing the faunal assemblages (see Carney, 2005 for a general review). In our study, depth was found to be significant for all the analysis performed. However, it is not a causative factor and other factors, such as temperature, high pressure and limited food availability have also been proposed as causal factors (Carney, 2005). Depth-related trends in density were different depending on the taxonomic group analysed. Teleosts showed a clear decreasing trend, similarly than elasmobranchs and others and both crustaceans and molluscs showed an increasing trend until a maximum (Labropoulou & Papaconstantinou, 2000; Colloca et al., 2003; Massutí & Reñones, 2005). The variance explained in the model by the rest of significant factors (year, area, effort and hydrographic characteristics) was quite low (less than 7%). In the case of year, the low variance explained seems to be more related to differences in temporal species-specific abundances than to assemblage species composition. The high rate of classification success for the test data set in the supervised machine-learning suggests the consistency of the observed species pattern throughout the examined years. Although there was not a clear trend by years, both elasmobranchs and crustaceans showed the highest values in 2002.

Geographical variations found can be related to the different hydrodynamic and geo-morphology conditions, which can vary between these closed geographical areas, similarly to other studies (Abelló et al., 2002b; Massutí et al., 2004; Gaertner et al., 2005). Spatial differences can also be related to differences in fishing exploitation (Gristina et al., 2006; Dimech et al., 2008; Moranta et al., 2008). Larger values of density were detected in the eastern and northern areas, where fishing

Table 4 Results of the redundancy analysis for the density (abundance in n/km^2 and biomass in g/km^2) matrix of the species

	Depth * Area * Year * Effort * Temperature * Velocity * Primary production					
	Effect	Cov	Trace	EV (%)	*F* ratio	*P* value
Abundance	Full model		0.595	59.5	10.941	0.002
	Depth	A, Y, E, T, V, PP	0.278	27.8	92.097	0.002
	Area	D, Y, E, T, V, PP	0.028	2.8	3.075	0.002
	Year	D, A, E, T, V, PP	0.033	3.3	1.539	0.016
	Effort	D, A, Y, T, V, PP	0.018	1.8	2.965	0.006
	Temperature	D, A, Y, E, V, PP	0.023	2.3	7.661	0.002
	Velocity	D, A, Y, E, T, PP	0.060	6.0	19.850	0.002
	Primary production	D, A, Y, E, T, V	0.007	0.7	0.778	0.784
Biomass	Full model		0.576	57.6	10.104	0.002
	Depth	A, Y, E, T, V, PP	0.272	27.2	85.863	0.002
	Area	D, Y, E, T, V, PP	0.026	2.6	2.708	0.002
	Year	D, A, E, T, V, PP	0.027	2.7	1.234	0.080
	Effort	D, A, Y, T, V, PP	0.016	1.6	2.546	0.006
	Temperature	D, A, Y, E, V, PP	0.019	1.9	6.157	0.002
	Velocity	D, A, Y, E, T, PP	0.046	4.6	14.679	0.002
	Primary production	D, A, Y, E, T, V	0.009	0.9	0.967	0.510

The trace, the explained variance (EV), the *F* statistic and its significance (*P* value) for both the full model, which contains all the variables included in the model and for each individual variable after extracting the effect of the covariable is also indicated. *D* depth, *A* area, *Y* year, *E* effort, *T* temperature, *V* current velocity, *PP* primary production. Only non-correlated variables were included in the model

Table 5 Results of generalised additive models (GAM) applied to the different groups of species and all the species (Total), showing the dependent variable (abundance in n/km^2 and biomass in g/km^2), the explanatory variables (*D* depth, *A* area, *Y* year, *E* effort, *T* temperature, *PP* primary production), as well as the score, *R*-squared (R^2) and deviance explained (DE) values

	D	A	Y	E	T	PP	Score	R^2	DE (%)
Abundance									
Total	***	***	***	ns	ns	ns	0.421	0.178	80.0
Elasmobranchs	***	ns	***	+	ns	ns	0.507	0.078	46.9
Teleosts	***	***	***	ns	ns	ns	0.336	−0.023	82.7
Crustaceans	***	+	***	+	ns	ns	0.269	0.047	52.1
Molluscs	***	ns	***	ns	ns	ns	0.732	0.133	63.1
Others	***	***	***	ns	ns	ns	1.598	0.103	59.8
Biomass									
Total	***	***	***	ns	ns	ns	0.429	0.191	71.5
Elasmobranchs	***	ns	***	+	ns	ns	0.894	0.143	25.5
Teleosts	***	***	**	ns	ns	ns	0.190	0.125	79.2
Crustaceans	***	+	***	+	ns	ns	0.251	0.126	32.9
Molluscs	***	*	***	ns	ns	ns	0.592	0.386	51.4
Others	***	***	***	ns	ns	ns	1.840	−0.580	42.2

The significance of each explanatory variable (*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, $^{+}$ $P < 0.1$; ns: not significant or $P \geq 0.1$) is also indicated

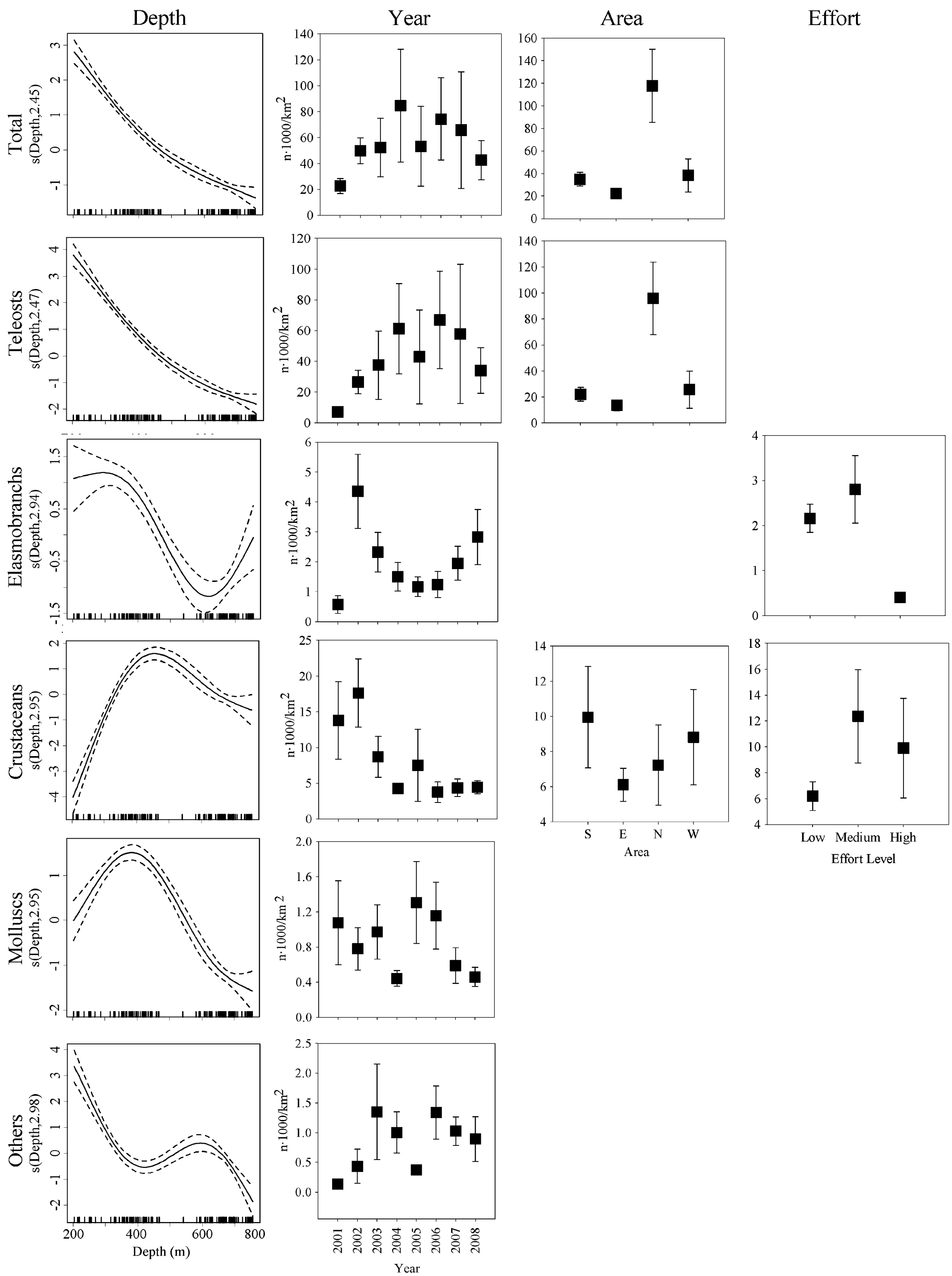

Fig. 3 Plots of the best significant generalised additive modelling (GAM) applied to the abundances of each of the taxonomic groups (total, teleosts, elasmobranchs, crustaceans, molluscs and others) for depth, and mean abundance values (n/km^2) for the significant factors year, area (*S* south, *E* east, *N* north, *W* west) and effort level (low: <500 days/year; medium: 500–1000 days/year; high: >1000 days/year). Error lines are standard errors

effort was lower. However, effort was only marginally significant for two groups, elasmobranchs and crustaceans. Larger values of elasmobranch density were found with low and middle effort. This trend can be related to the biological characteristics of these species, which made them particularly vulnerable to fishing pressure (e.g. Aldebert, 1997; Bertrand et al., 1998; Stevens et al., 2000). The Balearic Islands have been reported as an area of higher diversity of demersal elasmobranchs in comparison to the adjacent waters off the Iberian Peninsula (Massutí & Moranta, 2003). The differences found at the short spatial scale analysed in this study remarked the especially vulnerability of this species to fishing pressure. Crustaceans showed higher values of biomass with middle and high effort levels. For *A. antennatus*, small-scale temporal variability in catches has been related to the ability of fishermen to remove competitors at a differentially higher rate, leading to a higher catch of this species (Sardà & Maynou, 1998).

The use of TL for integrating different type of indicators in the assessment of the deep water fishery of the Balearic Islands has been revealed as a simple and useful tool for summarising large amount of both scientific and fishery data. By taking into consideration a wider range of factors than traditional assessment methods, the TL precautionary decision framework reduces the risk of missing important stock dynamics, environmental or ecosystem signals (Halliday et al., 2001). Its simplicity is also a strong argument for using this method and it does not require that previously used analyses be abandoned as their outputs can be incorporated into this more general framework. The method has potential not only for single species assessment, but also as a decision framework in management at the ecosystem level. In fact, indicators are needed to support the implementation of an ecosystem approach to fisheries (Jennings, 2005) and the complexity of exploited ecosystems forces to examine multiple indicators and a need to summarise them (Rochet & Trenkel, 2003).

For *N. norvegicus*, there was a quite clear improvement in the state of the population. The state of exploitation of the stocks of *N. norvegicus* in the Mediterranean, appears to be from slightly growth-overexploited to near the optimum level of exploitation depending on the area (Sardà et al., 1998). However, in the Balearic Islands there has been an overall negative trend in the landings of this species between 1986 and 1995 (Merella et al., 1998), although we should take into account that landings do not represent the state of the resources as well as CPUE does (Lleonart & Maynou, 2003). In fact, the fishing effort in the Balearic Islands has been gradually decreasing from 1994 to 2008 (personal communication). Recent results using more traditional assessment methodology (i.e. virtual population and yield per recruit analysis), showed that the species seems to be moderately exploited (Guijarro et al., 2009b). When comparing the different areas, Norway lobster population from the northern and southern areas are those in the better state, which are the two areas where the species is mainly landed by the trawl fleet (Merella et al., 1998). The worst estate was found in the eastern area, although this is the area with the lowest levels of effort. Thus, other factors than fishing pressure may influence this resource. Differences in population structure for this species have been related to exploitation levels (Abelló et al., 2002a) and environmental conditions such as sediment characteristics, related to its burrower behaviour (Maynou & Sardà, 1997). In the study area, short spatial differences on other crustaceans have been related to sediment characteristics and trophic webs (Guijarro et al., 2009a). The relative contribution of decapod crustacean feeding guilds closely related to the bottom resources are higher in the BsB (e.g., Maynou & Cartes, 2000; Cartes et al., 2008a) than in the AsB. This could explain the scarcity of this species in the eastern area, but not the presence and good state of *N. norvegicus* in the south, so probably the occurrence of both adequate sediment composition and prey availability seem to mark the short spatial differences found for this species.

For *A. antennatus*, differences between both sources of data can be explained by the high seasonal variability in the population dynamics of this resource. Large mature females aggregations in summer have been detected during the spawning period and a maximum recruitment of juveniles in the fishing grounds in the BsB have been detected during autumn–winter (Sardà et al., 1994, 1997; Tudela et al., 2003; Guijarro et al., 2008). This seasonal dynamics of the species also determines the fleet behaviour. In fact, there is an annual displacement of the trawl fleet targeting red shrimp from the southern fishing grounds to the northern ones during the spawning period, targeting the adult females

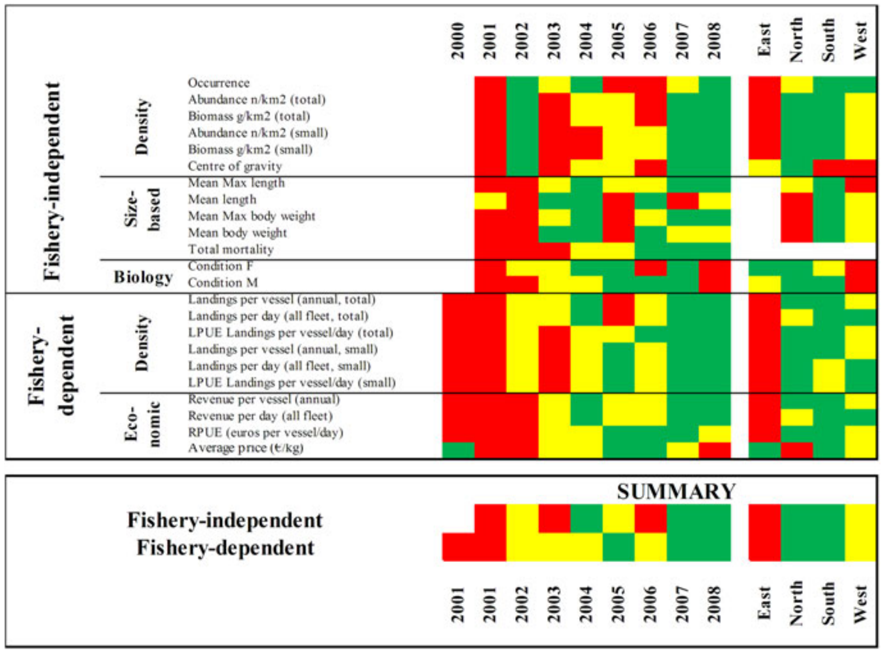

Fig. 4 Traffic Light tables displaying biological and economic indicators response for the Norway lobster *Nephrops norvegicus* in the Balearic Islands. *Red*: <33rd percentile; *yellow*: 33rd–66th percentiles; *green*: >66th percentile

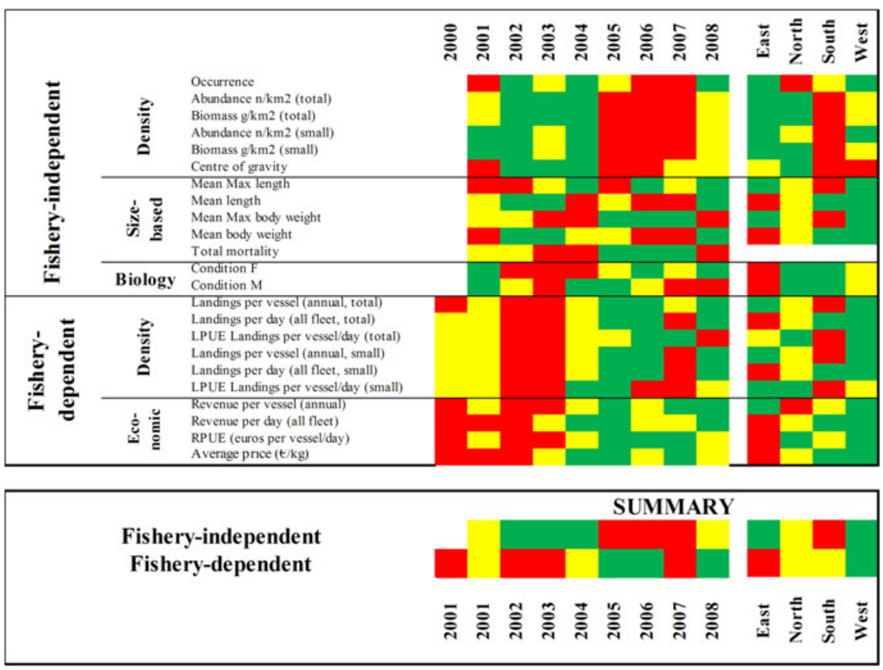

Fig. 5 Traffic Light tables displaying biological and economic indicators response for the red shrimp *Aristeus antennatus* in the Balearic Islands. *Red*: <33rd percentile; *yellow*: 33rd–66th percentiles; *green*: >66th percentile

aggregations (Guijarro et al., 2008; Moranta et al., 2008). In our case, fishery-dependent data provides better information for this resource than fishery-independent data, as the first one covers all the year while the second has been obtained during a concrete period of the year. Our survey data were obtained during spring, without spawning aggregations or recruitment processes. In this sense, fishery-dependent indicators showed an improvement in the state of this stock during the last years. In fact, the assessment of this species using non-equilibrium production models in this areas suggested that red shrimp is slightly under-exploited (Carbonell & Azevedo, 2003). It is important to remark that

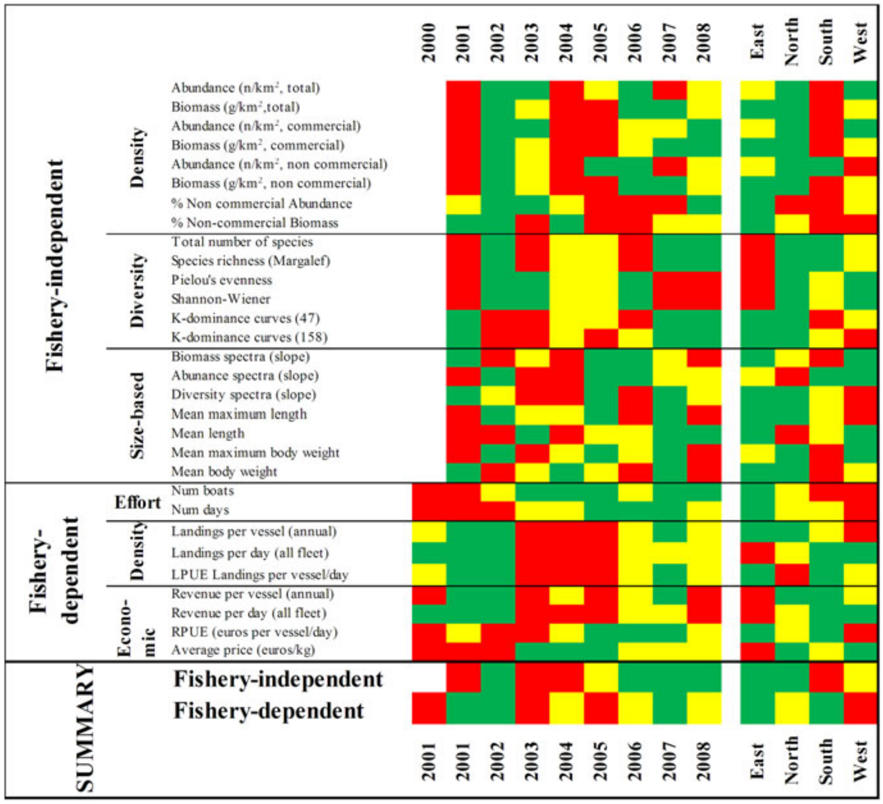

Fig. 6 Traffic Light tables displaying biological and economic indicators response for the upper slope assemblage in the Balearic Islands. *Red* <33rd percentile; *yellow* 33rd–66th percentiles; *green* >66th percentile, except for percentage of non-commercial species and effort variables (number of boats and number of days) in which opposite

condition showed differences between both sexes, with the lowest values of the series for males in the last 2 years, similarly of what has been detected from commercial fleet data (Carbonell et al., 2008). Geographically, the western area presented the best state of exploitation, although the fishing effort is high. This western areas has been pointed out as highly productive area (Guijarro et al., 2009a). In this area, higher abundance of suprabenthos and zooplankton has been detected (Cartes et al., 2008a), and also it is more influenced by the more productive waters coming from the Gulf of Lions (Champalbert, 1996; Bosc et al., 2004; Canals et al., 2006), which increases the primary production in the area and thus enriches the trophic chain (Estrada, 1996; Fernández de Puelles et al., 2004). These oceanographic conditions could favour *A. antennatus* more than *N. norvegicus* due to the differences on trophic webs already mentioned, as *A. antennatus* diet is based of mesopelagic preys (Cartes et al., 2008b).

At community level, different results have been found in the two assemblages analysed with TL. In the case of the upper slope, similar results have been found using fishery-dependent and fishery-independent data. In this case, it seems to be an improvement of the state of this assemblage during last years. This can be probably due to the decreasing trend in effort found especially from 2003. Also the highest values of abundance for elasmobranchs and crustaceans detected by other methods in 2002 was reflected both from the fishery-dependent and fishery-independent data. The eastern location seemed to be in a better state, which was the area with the lowest levels of effort. On the contrary, the western area, with high levels of effort, showed the worst state for this assemblage.

In the case of the middle slope, where *A. antennatus* is the most important species in the assemblage (around 30% in abundance) and represents near 80% of landings (Moranta et al., 2000), several differences have been found between both sources of information. Fishery-depended annual indicators seem to show an improvement in the state of this assemblage, while it seems the contrary for the fishery-independent data, especially for density indicators and size-based ones. When these indicators

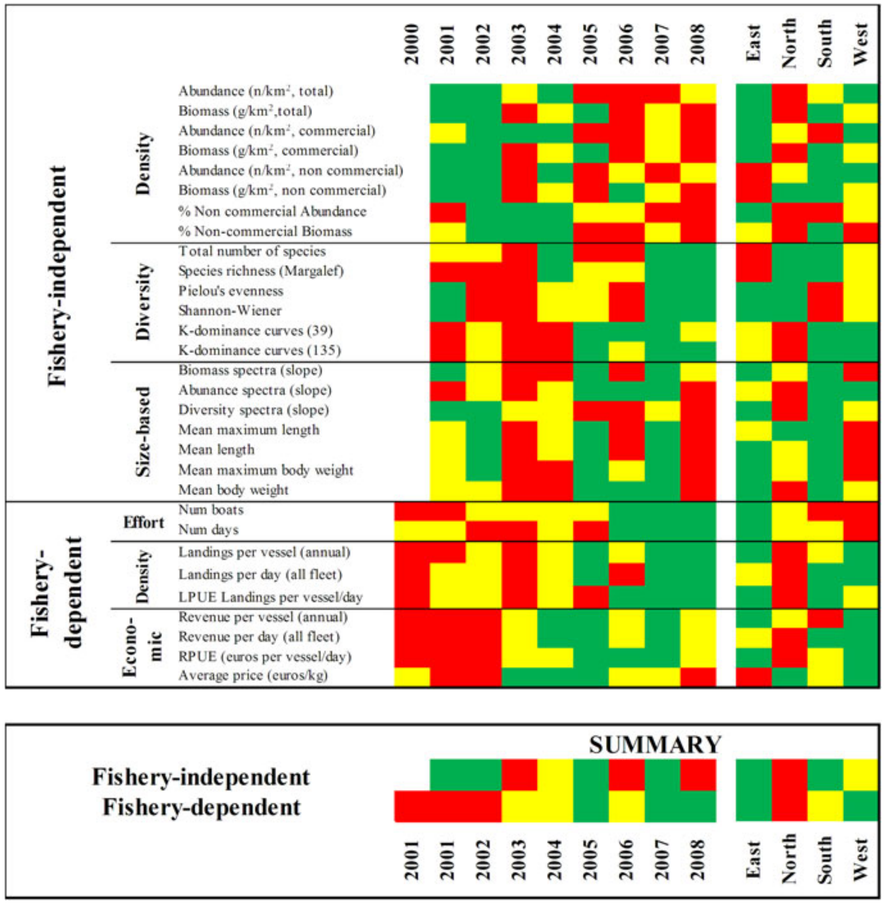

Fig. 7 Traffic Light tables displaying biological and economic indicators response for the middle slope assemblage in the Balearic Islands. *Red* <33rd percentile; *yellow* 33rd–66th percentiles; *green* >66th percentile, except for percentage of non-commercial species and effort variables (number of boats and number of days) in which opposite

were computed geographically, these differences were not so important. The better state was found in the eastern location but the worst in the northern, although this area presents intermediate levels of effort, which suggest that not only fishing pressure is the responsible of the state of this assemblage. Differences between both sources of information can also be attributed to the different species included in each case. Fishery-dependent data only included information from the landed species and not from those discarded, while fishery-independent data covered the entire nekton-benthic community. In the former set of data, discards from *A. antennatus* can be considered nil (Carbonell et al., 1999). These differences can also be attributed to the difference efficiency between the experimental and commercial gears which, in the case of commercial Italian trawl, have shown higher efficiency for benthic species when compared with the experimental and lower for some others released from the bottom as well as for the pelagic ones (Fiorentini et al., 1999). Experimental bottom trawl also showed a great variability of escapement values among species, which could affect the proportion rates of the species sampled during a standard survey as well as the size-frequency distribution as for some species the escape rate was size-dependant, like in the case of large-size classes escaping effectively from the trawl, probably because their greater swimming endurance (Dremière et al., 1999). Although this, for some species, the comparison from surveys and commercial fleet has given very acceptable results (Abella et al., 1999).

Conclusions

Although both fishing exploitation and the environment affect the population dynamics of marine resources (Hughes et al., 2003; Hsieh et al., 2006; Cury et al., 2008), their responses can be different depending on the species, taxonomic groups and their predominance in the communities. In this sense, although studies covering the entire epibenthic community are essential for implementing an ecosystem-based fishery management, species-based approaches are also necessary to understand single populations and to analyse how they contribute to the general trends of the entire community. However, analysis of indicators at single species level has provided a good response to know the status of the population, whereas the multi-species indicators have revealed some difficulties in interpretation (Ceriola et al., 2008). In fact, ecosystem considerations do not substitute for what is already known from a single species approach (Link, 2002) and the ecosystem-based approach can be implemented in systems with different levels of information and uncertainty (Pikitch et al., 2004). Finally, it is important to take into account that although fishery-independent information provides high quality and useful data, we have to take the results carefully for those species with important seasonal variations in their catchability and population dynamics and for those communities where these species predominate.

Acknowledgments The authors wish to thank to all the crew of the R/V *Francisco de Paula Navarro* and *Cornide de Saavedra* and all the participants who took part in the BALAR and MEDITS surveys. These surveys were carried out in the framework of the MEDER, DEMO, EVADEM and EVADEMED projects, financed by IEO and, from 2007, by the EU. Dr. Gabriel Jordà and Dr. Mar Flexas provided the data of the hydrodynamic model. This study was funded by an ECOSUMMER fellowship to BG from the Marine Curie Research Training Network under the EU Sixth Framework Programme.

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