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Ecological indicators and gear-based management of Algarve coastal fisheries

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Telma Lúcia Pereira dos Santos Coelho Conduto

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Nome: Telma Lúcia Pereira dos Santos Coelho Conduto.

Faculdade de Ciências do Mar e do Ambiente da Universidade do Algarve.

Orientador: Doutor Karim Erzini, Professor Associado com Agregação da Faculdade de Ciências do Mar e do Ambiente da Universidade do Algarve.

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Júri:

Presidente:

Doutor Adelino Vicente Mendonça Canário, Professor Catedrático da Faculdade de Ciências do Mar e do Ambiente da Universidade do Algarve.

Vogais:

Doutor Kostantinos Stergiou, Associate Professor, Aristotle University, Grécia;

Doutor Karim Erzini, Professor Associado com Agregação da Faculdade de Ciências do Mar e do Ambiente da Universidade do Algarve;

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Abstract

A number of ecological indicators were used to study the impact of fishing gear on the Algarve marine ecosystem. Catch composition, species richness, diversity, mean length, trophic level, percentage of mature and optimum sized fish and percentage of megaspawners were determined for the fish catches of each gear type. Four types of static gears (gill nets, trammel nets, bottom longline and semi-pelagic longline) with different mesh sizes or hook sizes represented the small-scale fisheries and were studied using data from experimental fishing trials, while commercial catches of two trawling types, crustacean trawling and fish trawling exemplified the industrial fisheries. Different species dominated the catches of the different main gears. Gill nets were clearly differentiated by the low trophic levels. Semi-pelagic longline caught larger fish with high trophic levels. Trammel nets also had high percentage of mature individuals in the catches, but also more non-target species. The trawlers affected juveniles of many species. Larger mesh sizes caught larger individuals, though not necessarily mature. The ordination procedure revealed how gear catches are best characterized by the different indicators and catch composition. Technical interactions were apparent when some gears affected juveniles of target species of other gears. Management recommendations such as minimum legal size, closed areas, gear restrictions and modifications are provided. Fishers participation in management can be enhanced by explanations of these simple indicators. Public participation can be extremely important for supporting unpopular management measures.

Resumo

Diversos indicadores ecológicos foram aplicados na avaliação do impacto das diferentes artes de pesca no ecossistema da costa algarvia. Composição das capturas, riqueza específica, diversidade, comprimento médio, nível trófico, percentagens de peixes maduros, de comprimento óptimo e altamente fecundos foram determinados para as capturas de peixe de cada tipo de arte. Quatro tipos de artes fixas (redes de emalhar, redes de tresmalho, palangre de fundo e palangre semi-pelágico) com diferentes malhagens ou anzóis representaram a pequena pesca e foram estudados através de experiências de pesca, enquanto as capturas comerciais de dois tipos de arrasto, o arrasto de crustáceos e o arrasto de peixe, exemplificaram as pescas industriais. Diferentes espécies dominaram as capturas das diferentes artes. A rede de emalhar foi diferenciada pelo baixo nível trófico das capturas. O palangre semi-pelágico capturou indivíduos com maior tamanho, mais altas percentagens de adultos e com alto nível trófico. As redes de tresmalho capturaram também altas percentagens de adultos mas também afectaram muitas espécies acessórias. Os arrastos afectaram juvenis de muitas espécies. Maiores malhagens capturaram maiores indivíduos mas não necessariamente adultos. A ordenação revelou como as capturas de cada arte eram caracterizadas pelos diferentes indicadores e pela composição especifica. Interacções técnicas foram aparentes quando algumas artes afectaram juvenis de espécies alvo de outras artes. Recomendações de gestão foram providenciadas como o tamanho mínimo, áreas restritas ou limitações e modificações nas artes. A participação dos pescadores na gestão pode ser acentuada por explicações destes simples indicadores. O envolvimento dos consumidores pode ser muito importante para forçar medidas de gestão menos populares.

Keywords: *ecological indicators; gear-based management; fisheries sustainability; scientific advice; stakeholders involvement; Algarve coastal fisheries.*

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1. Introduction

Natural resources are being depleted much faster than these can replenish themselves, many of the world fisheries are not maintained at sustainable levels and many commercially important stocks have already collapsed or been reduced to very low levels (NRC, 1999; JENNINGS *et al*., 2001; PAULY *et al*., 2002) but human impacts are still accelerating in their magnitude, rates of change and diversity of processes responsible for changes over time (JACKSON *et al*., 2001).

Fishing affects fish communities through selective removal of target species, bycatch, habitat modification, resulting in changes in overall biomass, species composition and size structure. The extent of the response depends on life history characteristics of the individual species, trophic interactions among species and the type of changes in the physical habitat (BIANCHI *et al*., 2000; FRID *et al*., 2005).

Fisheries management consists of applying a set of fishery control measures in order to bring some measured parameter of a fish stock towards a specific target, with the objective of optimising some specified aspect of the fishery (PATTERSON, 1992). The main biological objective of fisheries management is to protect the resources from overexploitation that would jeopardize future production, i.e. maintain sustainability. Fishing activities are sustainable when do not cause or lead to undesirable changes in biological and economic productivity, biological diversity or ecosystem structure and functioning from one human generation to the next. In many cases, this implies a need to rebuild populations of exploited species and to promote recovery of ecosystems from effects of overexploitation (NRC, 1999; JENNINGS *et al*., 2001). Unsustainable fishing practices arise from inappropriate incentives, high demand for limited resources, poverty, inadequate knowledge and (or) ineffective governance (GRAFTON *et al*., 2006). However, a historical perspective is crucial for remediation and restoration (JACKSON *et al*., 2001) (e.g. when a large part of the fish populations' distribution is outside the range of fishing operations and many large, old, fecund females remain untouched, sustainability in fisheries can be achieved (PAULY *et al*., 2002)).

The traditional single-species approach simplifies the system by omitting details of ecosystem complexity, ignoring the mixed-species aspect of a fishery and not reflecting the indirect effects of fishing that can have more important impacts on marine ecosystem structure and dynamics than do removals of the fish themselves. Problems that have arisen in the context of fisheries management based on single species approaches include stock collapses, shifts in trophic structure, habitat degradation, incidental take and bioeconomic problems (BOTSFORD *et al.,* 1997). Management of fisheries must consider the whole system to provide a realistic ecological perspective and move towards sustainable fisheries. Ecosystem-based fishery management acknowledges the critical role of ecosystem processes starting with the ecosystem rather than the target species and its overall objective is to sustain healthy marine ecosystems and the fisheries they support. However, it requires a complex understanding of ecosystem dynamics and the organization of component communities, as well as the dependence of humans on these ecosystems. To some extent, ecosystem-based management is limited by the data requirements and insufficiency of data and fluctuating environments mean there are commonly substantial uncertainties in analysing the effects of fishing on the ecosystem. Where knowledge is not enough, precautionary measures that favour the ecosystem should be adopted (BOTSFORD *et al.*, 1997; NRC, 1999; PIKITCH *et al.*, 2004).

The implementation of an ecosystem-based approach includes having ecosystem objectives (e.g. predator population health); bycatch concerns; multispecies assessments; modification of gears (e.g. to reduce, repel or exclude certain species); categorization of habitats according to their sensitivity to fishing; recognition of ecological dependence (e.g. limit catches of target fish that are prey of another targeted species); genetic diversity (e.g. maintain large populations and avoid local depletions); assessment of the impact of the management measures (FRID *et al*., 2005). The challenge of ecosystem-based fisheries management is to catch the target fish at a sustainable level with minimum effects on the size structure of the target population, non target species, trophic chain and physical environment (BOTSFORD *et al*., 1997; CHUENPAGDEE *et al*., 2003; FRID *et al*., 2005). Nevertheless, harvesting at a sustainable rate can, with a small change in age of selection, become unsustainable and lead to commercial extinction of the stock unless remedial action is taken (MYERS and MERTZ, 1998).

Decisions have to be made before the resources are depleted (NRC, 1999) and objectives must be clearly specified (what is to be achieved or what needs to be avoided) and to determine whether objectives are met, the manager needs indicators (GARCIA and STAPLES, 2000; JENNINGS *et al*., 2001) to summarize large quantities of information into a few relevant signals (GARCIA *et al*., 2000). Ecological indicators can be used to describe the state of the ecosystem (Table 1.1) and to assess strategies regarding sustainable development objectives and action. They need to capture the complexities of the ecosystem yet remain simple enough to be easily and routinely monitored and should meet the following criteria: be easily measured, be sensitive and responsive to stress (e.g. fishing) in a predictable manner, be anticipatory (i.e. identify a substantial change before it occurs), be integrative (i.e. when aggregated with other indicators provide an assessment of the entire system), have low variability (DALE and BEYELER, 2001; PIET and JENNINGS, 2005), be readily understood and cost-effective (SHIN *et al*., 2005). Reference points for the indicators must be derived from broader management objectives and they may be targets (to be achieved) or limits (to be avoided) while indicators are determined from measurements in catches (SAINSBURY *et al*., 2000).

Management of the fishery has also to consider fisher behaviour (e.g. gear used, target species, fishing locations, vessel and crew) and not just focus on the resource. Gear type and use vary in efficiency of fish capture, selectivity and composition of catches. A well managed fishery is expected to use gear that catch most of the available species at sizes that do not undermine sustainability. In this view, an understanding of gear impact on the ecosystem and potential resource overlap between gears is important for management decisions as different gears may differentially impact the exploited stocks (AGNEW *et al.*, 2000; PELLETIER and FERRARIS, 2000; MCCLANAHAN and MANGI, 2004; FRÉDOU *et al.*, 2006). Restraints that affect how, when and where the fish are caught can ensure that ecosystem functions that support fisheries productivity are preserved (ALLISON and ELLIS, 2001).

Detailed scientific information must be translated to recommendations useful to managers and applied to policy and decision-making through a policy dialogue (RAAKJÆR *et al*., 2007). Policy makers and other stakeholders sometimes do not use information because it is not communicated to them in a way that is relevant and understandable. Fishing quotas are decided on the basis of political considerations, largely ignoring the scientific advice and typically legalizing catches beyond safe levels, risking the eventual collapse of fish stocks rather than social or political conflict (BOTSFORD *et al*., 1997; FROESE, 2004). Currently in the North Sea there are more stocks outside safe biological limits than ever before, though scientific advice has been given for decades. However, advice has been available for only a limited number of species and stocks (FRID *et al*., 2005) and changes in demand have made more resources susceptible to overexploitation.

Ecological indicators can allow a more easy understanding of the impact of gears in the ecosystem and translate complex scientific information to more stakeholders, including fishers, fish dealers, supermarket managers, consumers and politicians (e.g. FROESE, 2004).

Table 1.1 Examples of application of ecological indicators.

Indicator	**Main results**	**References**
Trophic level, Mean Length, Mean Weight, Mean Maximum Lenght	Downward trends over time reflected changes in fish community structure due to heavy exploitation	NICHOLSON and JENNINGS, 2004 PIET and JENNINGS, 2005
Size spectrum slope	Steepens under long term fishing pressure, which was related with the level of exploitation, as larger fish were captured	BIANCHI *et al.*, 2000 DUPLISEA and CASTONGUAY, 2006
Fishing in Balance index	Reflected the expansion of the fishery and decline in total catches in the long term	CURY *et al.*, 2005b
Richness, Diversity, Trophic level, Size	Gear selectivity highly affected the species and size of captured fish on the short-term	McCLANAHAN and MANGI, 2004
Mature specimens, Optimum length and Megaspawners in the catch	Fisheries highly affected fish stocks when capturing undersized fish or very large specimens	FROESE, 2004
Functional groups biomass, Biomass of an indicator population	The decline of important fish stocks, greatly affected by fishing, was followed by the increase of other groups of species	METHRATTA and LINK, 2006

The purpose of this study is to describe the impact on the ecosystem of artisanal fisheries and trawl fisheries in terms of the diversity, species composition, size and life history stages in catches and trophic level of the catches, describe the competition between gears with the ecological indicators, demonstrate how ecological indicators can be translated and influence the general public and provide suggestions on how ecological indicators can be used to improve management actions.

2. Materials and Methods

2.1 Data sources

The data used in the present study came from gear selectivity experiments and projects on the bycatch of commercial fishing. For a more detailed description of the sampling design and methodology see ERZINI *et al*. (1999): gill net and bottom longline fisheries; ERZINI *et al*. (2000; 2001a): semi-pelagic longline fishery; ERZINI *et al*. (2001b) and STERGIOU *et al*. (2006): trammel net fishery; BORGES *et al*. (2000; 2002) and ERZINI *et al*. (2002): trawling fisheries.

2.2 Study site

Studies were undertaken along the Algarve coast at depths from 15m to 700m and fishing sites were chosen according to the traditional activities in the area (Figure 2.1).

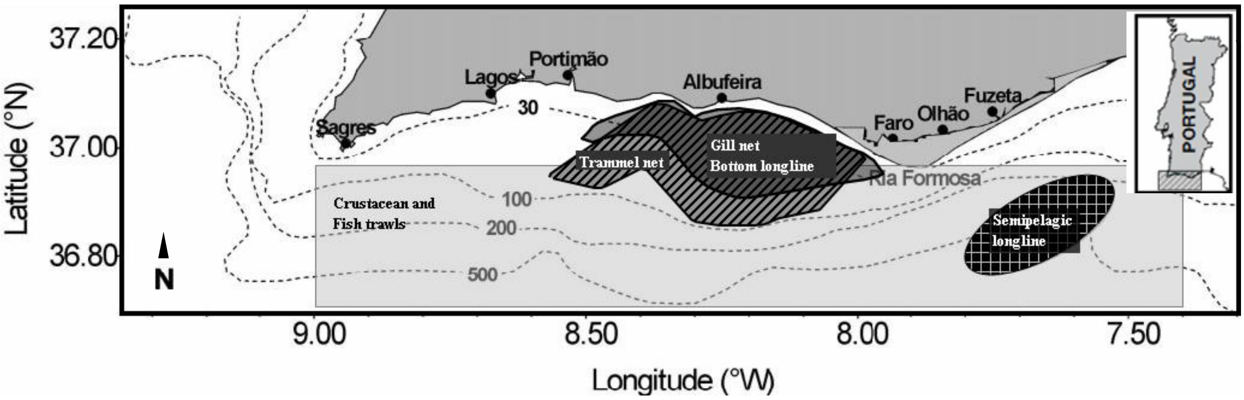

Figure 2.1 Map of the Algarve (southern Portugal, north-east Atlantic) with the representation of the traditional fishing grounds for each gear. The dashed lines represent the isobaths (m) (adapted from ERZINI *et al*., 2001a).

2.3 Fishing gears and sampling procedure

The fishing tactic (or *métier*) is described by the combination of the fishing location, the gear to use and, in some cases, the target species or group of target species. Though target species may not be reflected accurately in the catch, they are by definition tied to the fisher decision (e.g. PELLETIER and FERRARIS, 2000).

Six different fishing gears were studied. Four main static gears were sampled in fishing experiments of artisanal small-scale coastal fisheries: bottom longline, semi-pelagic longline, gill net and trammel net, where small scale fishing vessels were used for the fishing trips. For industrial fishing, the studied gears were trawlers (active gears): crustacean trawl and the fish trawl. The different fishing tactics targeted several species and fishing took place at depth ranges, which included the continental shelf and the continental slope (Table 2.1).

Besides the type, static gears were further differentiated by technical characteristics; longlines by hook size; gill nets by mesh size; trammel nets by the inner and outer panel mesh size combinations.

A description of the gears used, fishing grounds, depths and target species is given in Table 2.1. Sampling took place using commercial small scale fishing vessels and professional fishers carried out all fishing operations.

The nets and the longlines are static gears and represent the small-scale fisheries. They were constructed according to design specifications appropriate for each *métier* and the fishing technique applied in the fishing experiments was as similar as possible to the traditional fishing activities. Fishers selected fishing grounds in traditional areas, accordingly to the gear in use, in order to ensure the highest possible catches. Normal artisanal fishing operations were carried out regarding setting time, soak duration and hauling of the gear.

Table 2.1. Gear size designations, fishing location and depth ranges, main target species for each gear and reference publications.

Gear and gear designation	**Gear sizes and designations**	**Fishing location and depth**	**Target species**	**References**
Gill net G	Mesh size (nominal bar length): 25 mm – G1 30 mm – G2 35 mm –G3 40 mm –G4	Albufeira-Faro: 15 m – 60 m	Mullet (*Mullus surmuletus*)	ERZINI *et al*. (1999)
Bottom longline L	Hook size: 11 – L1 12 – L2 13 – L3 15 (smallest) – L4	Albufeira-Faro: 15 m – 60 m	White sea breams (*Diplodus* sp.) Red sea breams (*Pagellus* sp.)	ERZINI *et al*. (1999)
Semi-pelagic longline Ls	Hook size: 5 – Ls1 7 – Ls2 9 – Ls3 10 (smallest) – Ls4	Faro –Fuzeta: 200 m – 700 m	Hake (*Merluccius merluccius*)	ERZINI *et al*. (2001a)
Trammel net Tr	Inner / outer mesh size: 100/600 mm – Tr1 100/800 mm – Tr2 120/600 mm – Tr3 120/800 mm – Tr4 140/600 mm – Tr5 140/800 mm – Tr6	Albufeira-Faro: 15 m – 100 m	Cuttlefish (*Sepia officinalis*) Flatfish (Soleidae)	STERGIOU *et al*. (2006) ERZINI *et al*. (2006)
Crustacean trawl Tw1	Tw1	Algarve coast: 200 m – 500 m	*Parapenaeus longirostris* *Aristeus antennatus* *Nephrops norvegicus*	MONTEIRO *et al*. (2001) ERZINI *et al*. (2002) BORGES *et al*. (2000; 2002)
Fish trawl Tw2	Tw2	Algarve coast : 50 m – 300 m	Chub Mackerel (*Scomber* sp.) Hake (*Merluccius merluccius*)	ERZINI *et al*. (2002) BORGES *et al*. (2000; 2002)

RUTTAN *et al*. (2000) defined fishery scale in terms of vessel size or catch capacity. Low catches and smaller boats are typically associated with smaller crews, shorter travel distances and a greater degree of local consumption of catch, while higher catches and larger boats need larger crews and often operate further from shore.

Nets

Gill nets of four different mesh sizes were used in 40 fishing trials. The nominal bar lengths were: 25, 30, 35 and 40 mm. The net was made of 0.30 mm green monofilament, 40 meshes deep, with a hanging ratio in the floatline of 0.5. The floatline was 7 mm diameter nylon, while the leadline was 5 mm diameter nylon. The lead weights were 30 g and were placed at intervals of 70 cm along the leadline. Floats were spaced by 1.60 m along the floatline. The experimental nets consisted of 250 m sections of each mesh size in a random sequence separated by a 20 m rope. A total of 750 m of each mesh size were used for the fishing. These fishing experiments took place on the continental shelf at shallow depths of 15-60 m.

The trammel nets were of green monofilament and had the largest mesh sizes; 600 and 800 mm mesh for the outer panel and 100, 120 and 140 mm for the inner panel. A total of 25 nets of each of the following six combinations: 100/600, 100/800, 120/600, 120/800, 140/600 and 140/800 were used. The gears were set in the afternoon or evening before sunset and hauled after sunrise. The different sets of nets, with each combination arranged in 5 groups with 5 nets, were joined together by a footrope, leaving a 2 m gap between them so that fish are not led from one combination to the adjacent combination, thereby introducing error. The trammel nets consisted of 150 nets, totalling 8900 m, with 2500 m, 3000 m and 3400 m of each of the inner mesh sizes (100, 120 and 140 mm, respectively). Overall, 10 fishing trials per season were done during 1999-2000. These fishing experiments occurred at depths between 15 m and 100 m.

A description of each net and the experimental design is given in ERZINI *et al*.(1999; 2006) and STERGIOU *et al*. (2006).

Longlines

Two different types of longlines were studied: bottom longline (no floats) fish on the sea floor for demersal species, while semi-pelagic longlines have floats at regular intervals that lift the mainline off the bottom and are used for species that may be feeding 20 to 40m above the bottom in deep water. Each of these longlines also had different hook sizes that can be distinguished in different *métiers*.

The bottom longline is made of a main line of 1.1 mm diameter monofilament with gangions of 0.5 mm monofilament, 80 cm in length and spaced for about 1.7 m. Four hook sizes of MUSTAD round bend spade end hooks (numbers 15, 13, 12, 11) were used. Five longline tubs were used, each with a longline with four sections of 100 hooks of every size. The baited longline is set one to three hours either before sunrise or sunset and retrieved one to two hours after sunrise or sunset, respectively. Overall, 40 experimental fishing trials were carried out. These fishing experiments took place on the continental shelf at shallow depths of 15-60m.

The semi-pelagic longline used consists of a 1.60 mm diameter monofilament main line with 0.90 mm diameter monofilament gangions of approximately 1.2 m attached without swivels, directly to the mainline, at intervals of approximately 1.8 m. The longlines are stored in plastic tubs with cork rims. Four hook sizes of the brand SIAPAL were used: 10 (smallest), 9, 7 and 5 (largest), with numbers 7, 8 and 9 being the most commonly used by the fishers. Each tub consisted of only one hook size. The longline is baited on the way to the fishing ground and is set by placing a tub on a platform at the stern and using the momentum of the boat to pay out the longline. The crew attaches glass balls to lift the longline off the bottom at intervals of 48 hooks (for tubs with 144 hooks) or 40 hooks (for tubs with 120 hooks). The longline is weighted down with small rocks at regular intervals. The length of the longline is 10-15 km. To retrieve the longline, a hydraulic hauler is used to lift the large weights and the longline rises to the surface due to the expanded gas bladders of the caught fish. As the longline is hauled, the floats and weight are removed and the longline is stored in the tubs. Typically, the fishing trips started during the night and took 17-21 hours. A total of 64656 hooks were fished in 1997 and 51000 in 1998 in 10 fishing trips per year. These fishing experiments took place at depths between 200-700m on the continental slope. A description of each gear and the experimental design are given in ERZINI *et al*. (1999; 2001a).

Trawls

Trawls, representing industrial fishing, were distinguished based on the fishing strategy, with target species, fishing tactic and depth being distinct for the two trawl *métiers*. The chosen fishing grounds and the fishing operations were based on economic decisions taken by the trawl skipper after they leave the port. A description of the trawls and the experimental design is mentioned in ERZINI *et al*. (2002) and MONTEIRO *et al*. (2001). Crustacean trawlers fished at average depths greater than 200m, with the majority of tows taking place on the upper continental slope between 200 and 500m. Fish trawlers generally fished on the continental shelf between 100 and 200m but some tows were as shallow as 50m and others deeper than 300m. As the trawls target different species at different fishing depths with different fishing strategies, they are considered *a priori* distinct *métiers* (BORGES *et al*., 2002).

Scientific observers accompanied the fishers during each fishing trip. The catch coming on board all small scale fishing vessels was sorted by each gear size combination. Each specimen was measured (total length of fish, carapace length of crustaceans and mantle length for cephalopods) to the nearest 1 mm in the case of static gears (ERZINI *et al.*, 1999, 2001b). In the case of the trawls, the whole catch or at least a randomly selected 30 kg sub-sample of every haul was sorted to species level and then counted, weighed (to the nearest g) and measured (to the nearest 5 mm) (ERZINI *et al.*, 2002).

2.4 Analysis methodology

2.4.1 The data

A data matrix with relative abundances of all fishing trips of each gear size with species as variables was built. Only fishing trips with nonzero catch were considered. For each trip, absolute catch was transformed into a catch profile (i.e. relative species composition) by dividing each catch per species (in numbers) by the total catch of the trip. This removed the differences in catch levels between trips, which are often linked to both the time of the year, the crew size and the gear size (PELLETIER and FERRARIS, 2000).

Fish species considered rare were excluded from this analysis. The criterion for inclusion of a species in the analysis was to represent >1% of the total catch (by number) in at least one of the size categories of the main types of gears.

This study was based on a total of 20 categories of gear belonging to six main types of gear: gill net, bottom longline, semi-pelagic longline, trammel net, crustacean trawl and fish trawl. The cumulative percentage contribution of each species (in numbers) was calculated in order to identify the most important species.

2.4.2 Species relative composition of catches

Higher abundances of target species in the catches are a common goal of the different gears. Species relative abundance in catch composition for each gear and gear size was used to determine if the different gears achieve this objective.

2.4.3 Indicators

The selection of indicators from the large number described in the literature was based on the available data, their common use, their ecological meaning and sensitivity to fishing pressure (e.g. BIANCHI *et al.*, 2000; ROCHET and TRENKEL, 2003; NICHOLSON and JENNINGS, 2004; TRAVERS *et al*., 2006). Three main categories of ecological indicators are considered in this study: size-based, species-based and trophodynamics indicators of the catch by main gear type and each gear size (Table 2.2). The indicators were calculated per fishing trip and then averaged. Data were pooled across all fish species.

2.4.3.1 Size-based indicators

Fishing is always size-selective, generally targeting larger, more valuable fish, modifying the structure and functioning of fish assemblages with consequences for productivity and resilience of some stocks. Size-based indicators may then provide a relevant integration of the effects of fisheries on the community structure and processes. The only data required is the size distribution of organisms (SHIN *et al*., 2005). For this analysis the data set consisted of the length frequency of the fish catch on daily trips.

Mean length

Mean length of the captured fish reflects the impact of the fishing gears on the fish community (or in the population when considering mean length at the species level) and quantifies relative abundances of large and small individuals of fish species in the catch. Relative abundances of the different fish species were summed for each 1 cm length interval.

Mature fish, Optimum length fish and Megaspawners

Mature fish is the percentage of the mature specimens in the catch. The target is 100%, as all fish should spawn at least once before they are caught in order to rebuild and maintain the healthy spawning stock (FROESE, 2004). Length at maturity accounts for changes in the relative abundance of species with different life history parameters (SHIN *et al*., 2005).

Optimum length is measured as the percentage of fish caught at optimum length, i.e. the length where the maximum yield and revenue can be obtained. The target would be to catch all fish (100%) within ± 10% of optimum length (FROESE, 2004).

The megaspawners indicator is measured as the percentage of old, large fish in the catch, i.e. fish larger than the optimum length plus 10% (FROESE, 2004). The larger individuals in a population can enhance the successful reproduction, recruitment and survival (BIRKELAND and DAYTON, 2005). Here the target should be 0%, i.e. no megaspawners being caught (FROESE, 2004). The megaspawners indicator was chosen because there is evidence that older fish produce more and better eggs as well as pass on their successful genes (LONGHURST, 2002). Maturation size, optimum length and megaspawners length were obtained from empirical equations of FROESE and BINOHLAN (2000) or FISHBASE (FROESE and PAULY,1998) and SANTOS *et al.* (2003) for European hake.

2.4.3.2 Species-based indicators

The Shannon-Wiener index (H’) is a mixed indicator that provides information about both species richness and species evenness and jointly with species richness can provide information about changes in ecosystem structure (GREENSTREET *et al*., 1999). Because fisheries are relatively species selective, but also induce indirect effects on non-targeted species, diversity index and number of species may be sensitive to gear impact.

2.4.3.3 Trophodynamics indicator

The food web is assumed to reflect the main interactions between individuals in a fish community (TRAVERS *et al*., 2006) and trophic level is expected to increase with size (SHIN *et al*., 2005).

Mean trophic level of the catch

Mean trophic level of the catch was the indicator suggested to evaluate the fishery induced impact on the trophic structure of the exploited assemblage (PAULY *et al.*, 2001, 2002) by the different gears. It is calculated as the average of the species trophic levels weighted by species relative biomass. Because the trophic level of a fish may change as it grows, using a fixed mean trophic level per species is an approximation used for highlighting the contribution of a species to the community and not changes in the trophic role of species in the food web (TRAVERS *et al*., 2006). Because direct observations of diet compositions were not available, trophic level estimates for each fish species are based on diet composition data compiled in FISHBASE (FROESE and PAULY, 1998) where diet information and standard errors may also be found. The trophic level of each fraction of the diet of the fish is used to calculate the mean trophic level for the species (PAULY *et al*., 2001; 2002). Weights of individuals were used directly if available and for individuals with no available weight, but with recorded length, individual length was converted to weight from species-specific length-weight regressions (DUPLISEA and CASTONGUAY, 2006): Weight=b*Length^{a}, where b and a are parameters calculated in other studies of fish populations (BORGES *et al.*, 2000, 2003; GONÇALVES *et al*., 1997; SANTOS *et al*., 2002) or available in FISHBASE (FROESE and PAULY, 1998). The formulae for calculating the different indicators are given in Table 2.2.

Table 2.2. Types of ecological indicators used for evaluating fishing impact.

Indicator	Notation	Description	Key references
Mean length	$\overline{L_{C_i}}$; L_{mid}	$\overline{L_{C_i}} = \frac{1}{C_i}\sum_{C_i} L$ (cm)	TRAVERS *et al.* (2006)
Percent of mature fish	L_{MAT}		FROESE (2004)
Percent of optimum size	L_{OPT}		FROESE (2004)
Percent of megaspawners	MEGA		FROESE (2004)
Shannon-Wiener index	*H'; Div*	$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$	HURLBERT (1971)
Number of species	*S*		
Mean trophic level	$\overline{TL}$	$\overline{TL}_k = \frac{\sum_{i=1}^{m} Y_{ik} TL}{\sum Y_{ik}}$	PAULY *et al.* (2001)

Note: *L*, body length of species *i*; C_i, abundance of fish of species *i* in the catch; p_i, proportion of total number of individuals of species *i*; *S*, number of species present in the catch; TL_k, mean trophic level of the catch for each trip; Y_{ik}, catch of species *i* in gear *k*; TL is the trophic level of species *i* for *m* fish species in the catch.

One-way ANOVA was used to test for differences in each indicator (mean length, trophic level, length at maturity, optimum length, megaspawners and diversity and species number) between main gears and across the different gears sizes for the static gears (gill net, trammel net and longlines) based on data for each fishing trip. When overall significance was found, pair-wise comparisons were computed using the Tukey honest significant differences test to determine which gears were different (QUINN and KEOUGH, 2002). For trawls (crustacean trawl and fish trawl), a *t-test* was used to test for gear specific indicator relationships. Diversity and number of species of the fish catches and whole catch were also compared with *t-test* for the main gear types.

2.4.4 Multivariate analysis

Multivariate analysis was performed in order to classify the different gear sizes in groups of similar métiers in terms of catch profile. The classification of the catches by gear and gear size allows identifying groups based on their species abundance composition and the respective indicators. Multivariate analyses were used to delineate gear differences in the structures of the catches and to detect patterns in the data that could not be found by analysing each variable (species) separately (QUINN and KEOUGH, 2002). The data consisted of the relative abundance of each fish species averaged for each gear size. Analyses were based on species-frequency data only, because information on weight was only available for some fishing trips. Relative abundances of the fish species observed are initially subject to severe transformation (square root) to ensure that the multivariate analysis also reflects patterns of variation in the less abundant taxa rather than being dominated by the most common species (FIELD *et al*., 1982).

Multidimensional scaling and clustering

To represent all pairwise dissimilarities between gears, multidimensional scaling (MDS) based on the Bray-Curtis (BRAY and CURTIS, 1957) dissimilarity matrix was used. The inter-relationships among individual catches were displayed graphically in two-dimensional ordination plots. Samples that grouped together in the ordination were most similar and the stress coefficient indicated the goodness of fit of the data (FIELD *et al*., 1982). A ‘stress coefficient’ less than 0.1 indicates that the configuration of objects is reliable (QUINN and KEOUGH, 2002; GRAY and KENNELLY, 2003).

Cluster analysis, classified by a hierarchical agglomerative cluster with the group average linkage method, based also on Bray-Curtis dissimilarities matrix of the same data was used to obtain a dendrogram that rearranged the groups inside the main gear types according to the different abundance patterns of their fish species composition. The lengths of the lines represent dissimilarity. Clustering has the disadvantage of once a group is formed from two or more objects, that group cannot be broken later in the process. The combination of clustering and ordination analyses was used to check the adequacy and mutual consistency of the obtained groups. If there are very dissimilar groups, then the different methods of how the dissimilarities between clusters and between clusters and objects are recalculated (linkage methods) will produce similar dendrograms (QUINN and KEOUGH, 2002). This approach was useful for providing insight into differences in gear/gear sizes and to distinguish different *métiers* based only on the fish catch.

Principal component analysis (PCA)

Due to the large amount of compiled data, it was necessary to obtain a geometrical representation of individuals, variables and relationships between them, thus providing a reduced description of the large data set which is helpful in exploring the structure of the data set and is easier to interpret than the initial data table (PELLETIER and FERRARIS, 2000).

Principal component analysis (PCA) is a useful tool to describe a fishery, since it provides information about the relative importance of species in the catch composition, as well as about the variance explained by the single components obtained (GARCÍA-RODRIGUEZ *et al.*, 2006) and can serve as a vetting tool to help identify redundant indicators (METHRATTA and LINK, 2006).

The reduction in the complexity of the original data set is by transforming data in principal components, thus standardising the linear combinations of the original variables, which further reflects the influence of the original variables in each component. The components are extracted so that the first explains the maximum amount of the variance, the second explains the main part of the remaining unexplained variance by the first and so on, maximising the variance (inertia) of the projections of the cases on each axis. PCA allows the reduction of the dimensions of the data table by retaining only the axes that explain up to a given part of the inertia of the data set (sum of the eigenvalues). The axes are ordered according to decreasing contribution to the inertia of the data set. This eliminates marginal effects that might blur the structure of interest in the data set (PELLETIER and FERRARIS, 2000). In addition, their graphic representation lets one determine which variables are better explained by each component, easily identifying the more discriminant variables (GARCÍA-RODRIGUEZ *et al.*, 2006). After averaging all trips for each gear size, PCA was applied on two matrices. One consisted of the transformed (square root) fish relative abundance as variables. In the second matrix the variables were the indicators (not normalized) applied exclusively to the fish catch. The chosen association matrix was the correlation matrix, which is based on variables standardized to zero mean and unit variance and is necessary when the differences between variances are to be ignored (QUINN and KEOUGH, 2002). PCA was used to separate indicators in multivariate ordination space relative to one another in terms of explanatory power and to examine indicator redundancies.

One-way analysis of similarity (ANOSIM) was performed on the square root of fish relative abundance data to test for differences in the structure of fish catches by each main fishing gear.

2.4.5 The ecological indicators at the species level

The knowledge of biological characteristics of the species that dominate the different catches and that drive the fishery dynamics (i.e. high commercial value) and how the different gears affect these species must also be considered for management purposes (AGNEW *et al.*, 2000; FRÉDOU *et al.*, 2006). The contribution of several species was analysed and for those with higher values of abundance a graph was plotted with the indicators of mature fish, optimum size fish, megaspawners and the minimum legal size when established (LEITE, 2005).

3. Results

The species that represented more than 1% of the total catch by number, in at least one gear category in this study, comprised a total of 47 fish species representing 27 families, 2 cephalopods, 5 crustaceans, 2 gastropods, 5 echinoderms, 1 ascidia and 1 polychaeta (Table 3.1). The final data set contained 779 cases (fishing trips of each gear size) with the 63 representative species as variables.

Despite the large number of species caught, the catches were dominated by only a few species in some of the fishing experiments. Four most abundant species accounted about 80% of the total catch from the semi-pelagic longline fishery; for the bottom longline the eight most dominant species contributed 80% while for gill net this number of species contributed 70% of the catch. For both trawls the contribution of the most abundant eight species decreases even more, to about 60% of the total catch. Only for the trammel net fishery is the small contribution of each species noticeable (15 species accounted for about 70% of the catch, with a considerable contribution of gastropods, ascidia, echinoderms and the cephalopod *Sepia officinalis* being one of the most abundant species caught by this gear).

Percentages of the commonest fish species differed among the various gears studied (Figure 3.1 to Figure 3.5). For instance, *Scomber japonicus* was most common in the gill net fishery with values around 10% of the total catch for the smaller mesh sizes and more than 25% for the largest one, while for the trammel net the values ranged from 4% to 12% with the largest mesh combination capturing a higher proportion of *S. japonicus*. For the fish trawl it was about 6% and for the bottom and semi-pelagic longline fisheries and for the crustacean trawl this species accounted for less than 3%. The red mullet *Mullus surmuletus* is a species that was caught almost exclusively with the smaller meshes of gill net (11%-13%). *Spondyliosoma cantharus* accounted for between 2%-6% of the gill net catches, 12% of the bottom longline catches and only around 0.2%-0.5% of the trammel net and both trawl catches.

Table 3.1 Relative abundance and cumulative abundance of the most important species. For description of species designations see Table 3.3.

	GEAR																			
Species code	Gill nets				Bottom longlines				Semi-pelagic longlines				Trammel nets						Crustacean Trawl	Fish Trawl
	G1	G2	G3	G4	L1	L2	L3	L4	Ls1	Ls2	Ls3	Ls4	Tr1	Tr2	Tr3	Tr4	Tr5	Tr6	Tw1	Tw2
Al_sub																			0.95%	0.43%
Ar_ant																			3.44%	6.45%
As_ara													3.25%	3.63%	3.36%	3.48%	3.54%	4.09%		
As_med													3.23%	4.46%	5.35%	4.95%	6.98%	7.67%		
As_rug													0.73%	0.99%	1.20%	0.63%	0.79%	0.92%		
Be_elo									6.98%	7.40%	5.40%	8.01%							0.08%	0.07%
Bo_boo	2.78%	0.72%	0.38%	0.04%	4.83%	6.04%	6.71%	7.91%	0.09%				1.54%	1.91%	1.89%	0.70%	0.87%	0.84%	1.74%	1.22%
Br_bra									1.95%	2.43%	2.45%	3.52%								
Ca_ape																			2.68%	3.13%
Ch_las													2.64%	1.55%	1.04%	1.30%	0.41%	0.21%		
Ch_obs													2.77%	1.43%	1.52%	2.49%	1.45%	1.32%		
Ci_lin	0.40%	0.79%	1.33%	0.72%		0.29%							1.16%	0.92%	0.52%	0.49%	0.36%	0.31%	0.65%	0.56%
Co_con	0.04%	0.12%		0.04%	6.38%	7.68%	3.81%	2.93%	0.44%	0.70%	0.57%	0.78%	0.01%	0.12%	0.17%	0.12%	0.06%	0.14%	1.53%	1.48%
Cy_oll													4.36%	4.47%	4.08%	4.72%	4.57%	4.25%		
Da_arr													2.58%	2.74%	2.06%	2.08%	1.52%	1.17%		
Di_bel	12.82%	16.80%	13.03%	5.61%	6.74%	6.20%	8.70%	15.12%					0.34%	0.19%	0.23%	0.22%	0.02%	0.01%	0.02%	0.10%
Di_cun	0.67%	0.57%	0.91%	0.76%									0.25%	0.21%	0.03%	0.04%	0.03%	0.04%		
Di_sar				0.63%	9.73%	9.44%	8.21%	3.87%					0.01%	0.07%		0.07%	0.10%	0.02%		
Di_vul	2.78%	8.21%	12.89%	7.88%	13.30%	17.23%	19.95%	24.07%					1.01%	1.15%	0.38%	0.47%	0.23%	0.17%	0.07%	0.04%
Ec_cor													0.73%	0.20%	0.24%	0.77%	1.47%	1.00%		
Et_pus									6.19%	11.24%	11.20%	9.24%							0.46%	0.33%
Et_spi																			1.35%	1.14%
Fi_sp.													0.89%	0.29%	0.63%	1.04%	1.55%	1.78%		
Ga_arg																			1.11%	1.20%
Ga_mel									21.33%	21.63%	18.25%	17.27%							3.69%	2.99%
Ha_did			0.02%	0.08%	0.08%	0.26%							1.14%	1.46%	0.57%	0.75%	0.21%	0.14%	0.08%	0.00%
Ho_med																			1.86%	0.72%
Le_cau									2.43%	1.73%	2.48%	2.33%								
Le_cav														0.15%	0.16%	0.11%	0.02%	0.02%	0.94%	0.35%
Li_aur		0.45%	2.38%	0.31%									0.14%	0.06%	0.04%	0.08%		0.03%		
Li_mor	0.29%	1.35%	0.39%	3.00%	0.08%	0.10%	0.06%	0.09%					0.10%	0.12%	0.07%	0.02%	0.08%	0.08%		0.01%
Ma_spp																			8.38%	5.30%
Me_mer	0.54%	0.40%	0.30%	0.46%					45.96%	39.83%	45.16%	41.92%	1.49%	1.45%	1.74%	2.05%	1.87%	2.50%	6.69%	4.65%
Mi_aze													5.19%	7.60%	5.08%	5.21%	3.57%	3.72%	1.59%	0.02%
Mi_pou																			11.62%	15.65%
Mu_sur	13.64%	11.20%	3.96%	1.05%									0.31%	0.17%	0.05%	0.28%	0.10%	0.17%	0.01%	0.33%
Ne_nor									0.16%		0.10%	0.14%							8.66%	2.94%
Ne_scl																			4.55%	3.69%
Pa_aca	8.92%	9.39%	7.94%	3.50%	16.01%	14.42%	14.50%	12.71%					3.78%	3.76%	1.60%	2.04%	1.94%	1.23%	0.50%	0.49%
Pa_ery	5.90%	9.11%	6.63%	6.04%	4.69%	4.24%	3.84%	3.71%					0.45%	1.03%	0.84%	0.76%	0.62%	0.84%	0.01%	0.30%
Pa_liv													3.22%	3.76%	4.00%	3.68%	3.82%	5.05%		
Pa_lon																			10.63%	16.26%
Pa_pag	0.58%	1.57%	1.20%	4.36%	1.84%	2.33%	2.11%	1.35%					0.55%	0.56%	0.60%	0.31%	0.46%	0.35%		
Ph_ble									0.87%	0.79%	1.29%	1.39%							0.63%	0.97%
Ph_mam													4.75%	4.42%	6.27%	4.39%	7.32%	6.73%		
Ph_phy	0.02%	0.17%	0.18%		0.51%	0.38%	0.52%	0.16%					3.40%	3.28%	4.35%	4.52%	2.72%	1.68%	0.08%	0.30%
Po_hen																			1.62%	0.33%
Ra_und													0.43%	0.36%	0.67%	0.84%	1.60%	1.58%		
Sa_pil	6.96%	4.05%	6.89%	7.09%	0.06%								4.41%	3.85%	4.81%	4.04%	2.96%	2.84%	1.24%	1.21%
Sc_can	0.01%								6.72%	4.76%	2.61%	1.41%	0.56%	0.25%	0.34%	0.67%	0.26%	0.36%		
Sc_jap	8.84%	11.51%	13.26%	25.95%	3.12%	2.76%	2.49%	2.04%	0.49%	1.47%	1.14%	1.96%	4.62%	5.29%	6.72%	8.23%	9.84%	12.82%	2.23%	6.13%
Sc_not	14.86%	6.33%	3.97%	2.32%	7.54%	6.45%	7.83%	3.32%					4.22%	4.66%	1.45%	1.58%	0.37%	0.47%	0.62%	0.48%
Sc_sco	0.25%	0.35%	0.32%	0.29%	0.06%								1.65%	1.65%	1.47%	1.54%	1.97%	1.86%	0.84%	1.61%
Se_cab	2.18%	1.03%	0.52%	0.32%	2.97%	2.25%	2.48%	1.72%					1.58%	1.52%	0.84%	0.93%	0.36%	0.17%		
Se_hep	0.07%	0.07%		0.04%			0.63%	0.83%					0.03%		0.06%	0.04%	0.01%		2.01%	1.58%
Se_off	0.91%	0.46%	1.56%	0.61%		0.11%	0.03%						8.82%	6.67%	10.61%	9.13%	9.14%	9.80%	0.01%	0.01%
So_sen						0.05%	0.08%						0.96%	0.99%	2.14%	1.34%	1.54%	1.49%		
So_vul													1.01%	1.09%	0.43%	0.97%	0.66%	1.06%		
Sp_can	2.29%	2.67%	6.02%	3.08%	12.65%	11.97%	12.02%	12.70%					0.49%	0.56%	0.42%	0.21%	0.26%	0.35%	0.53%	0.20%
Sp_gra													3.23%	4.00%	4.47%	4.21%	5.22%	4.62%		
Sp_mae	1.89%	0.28%	0.03%										0.01%		0.01%	0.03%	0.01%			
Tr_dra	1.87%	0.43%	0.91%	4.22%	5.83%	4.84%	2.42%	3.36%					2.30%	2.84%	2.50%	2.02%	1.68%	1.25%	0.01%	0.01%
Tr_tra	5.69%	5.22%	4.70%	7.36%	0.44%	0.47%	0.21%	0.38%		0.07%			1.45%	1.04%	1.17%	0.57%	1.40%	0.67%	1.22%	3.11%
Cumulative Total	95.19%	93.27%	89.73%	85.75%	96.85%	97.50%	96.59%	96.26%	93.62%	92.04%	90.66%	87.99%	85.78%	86.93%	86.17%	84.10%	83.96%	85.83%	84.35%	85.75%

Diplodus vulgaris and *D. bellottii* made the highest contributions to the bottom longline catches, with values ranging from 20% to 40%, with the smaller hook sizes catching the higher proportions. In the gill net fishery these sparids contributed 13%-25%, with the intermediate mesh sizes catching the higher proportions, but were almost completely absent in the other gear catches. *Merluccius merluccius* was the only species that was found in quantities higher than 40% (semi-pelagic longline catches); in both trawl catches it was present in about 5%; for the static net fisheries (trammel and gill net) the values were lower than 3% and 1%, respectively and it was not present at all in the bottom longline catches. *Micromesistius poutassou* made up more than 11% in crustacean and fish trawls catches, but was absent in the remaining gears.

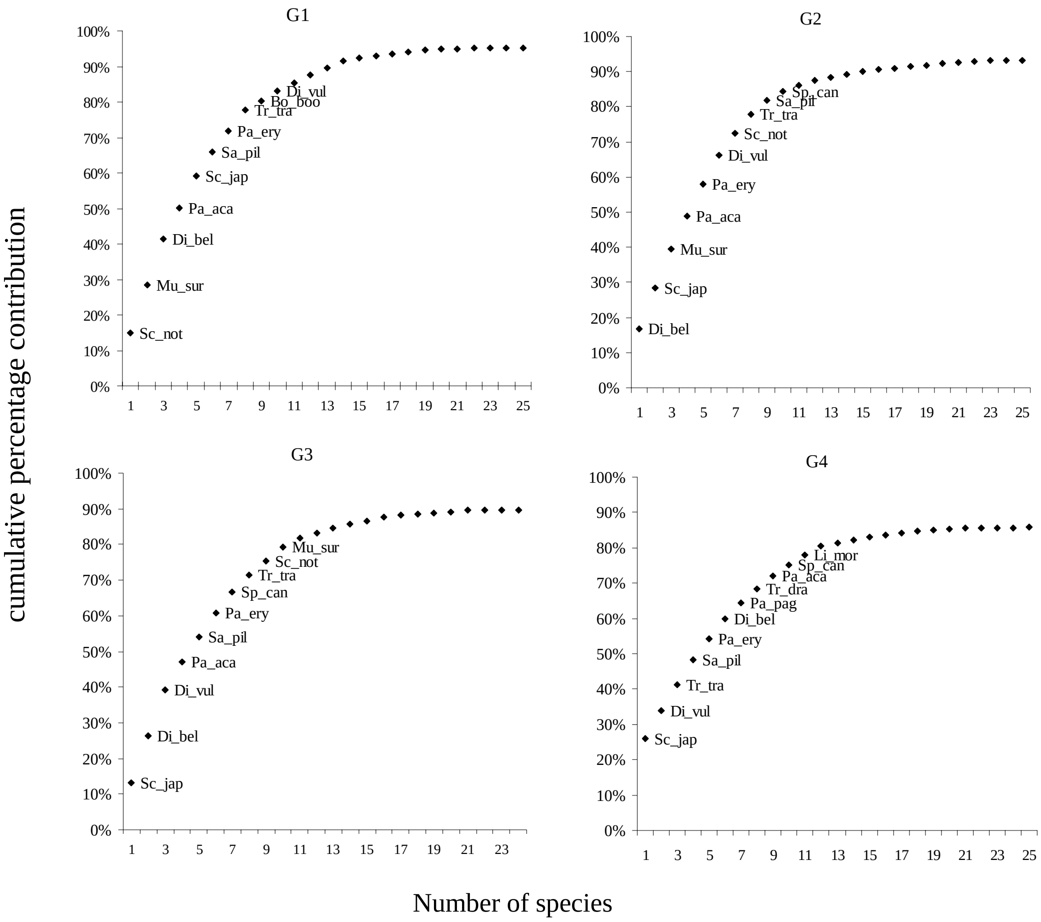

Figure 3.1 Cumulative percentage contribution of caught species by the different mesh sizes of gill net. For description of species designations see Table 3.3. The labels of the less important species were removed for clarity.

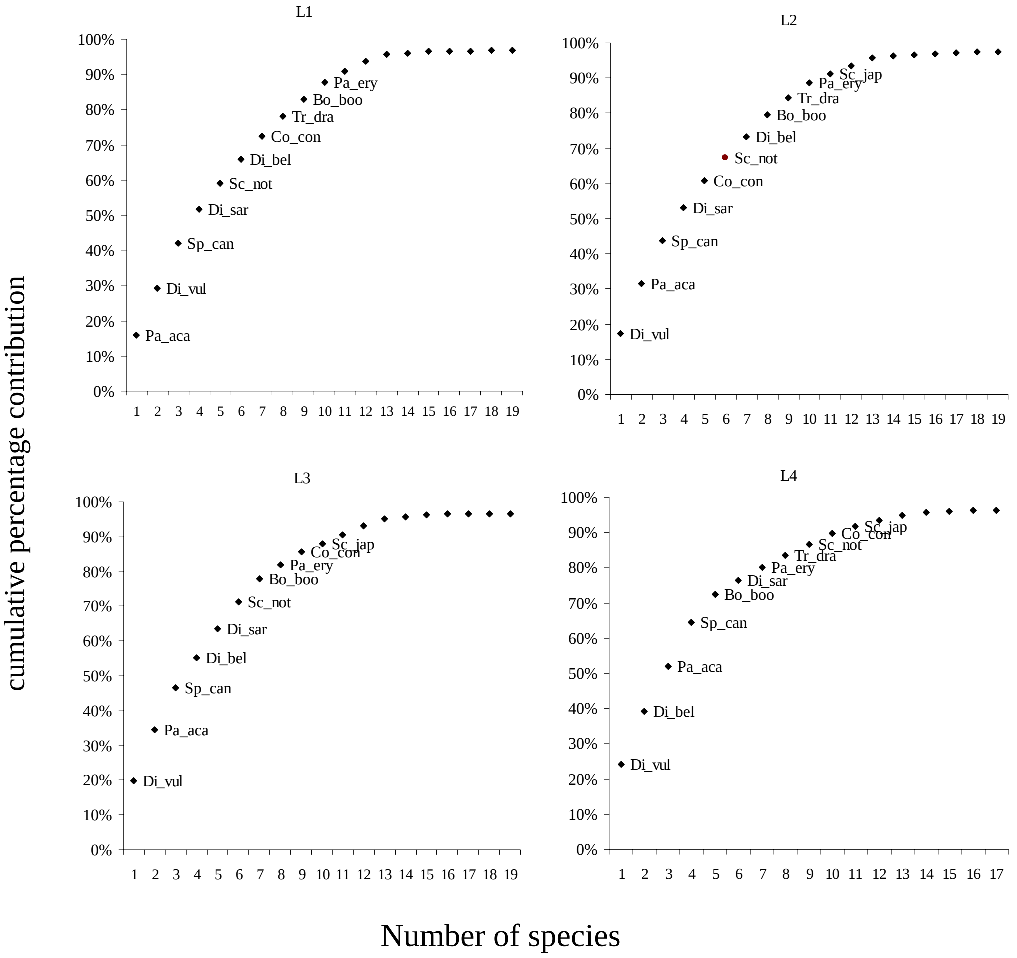

Figure 3.2 Cumulative percentage contribution of caught species by the different hook sizes of bottom longline. For description of species designations see Table 3.3. The labels of the less important species were removed for clarity.

The sparids *Pagellus acarne* and *Pagellus erythrinus* are present in higher proportions in gill net and bottom longline catches with values around 9%-18% and 16%-20%, respectively. These species account for 2%-4% of the catches of trammel nets, less than 1% of trawl catches and are absent in the semi-pelagic longline catches. The sparid *Diplodus sargus* was also a gear exclusive species as it was taken only by bottom longline, with the larger hook sizes attracting the highest proportions (9%).

The scorpionfish *Scorpaena notata*, was caught by all gears with the exception of the semi-pelagic longline. Values were very distinct among gear sizes: the smallest and the largest mesh sizes of gill net had values of 15% and 2%, respectively; the smallest hook of bottom longline had 3% while the other hook sizes had 7%; the combination with the smallest inner mesh size of trammel nets caught 4% with around 1% for the remaining combinations and also for trawls.

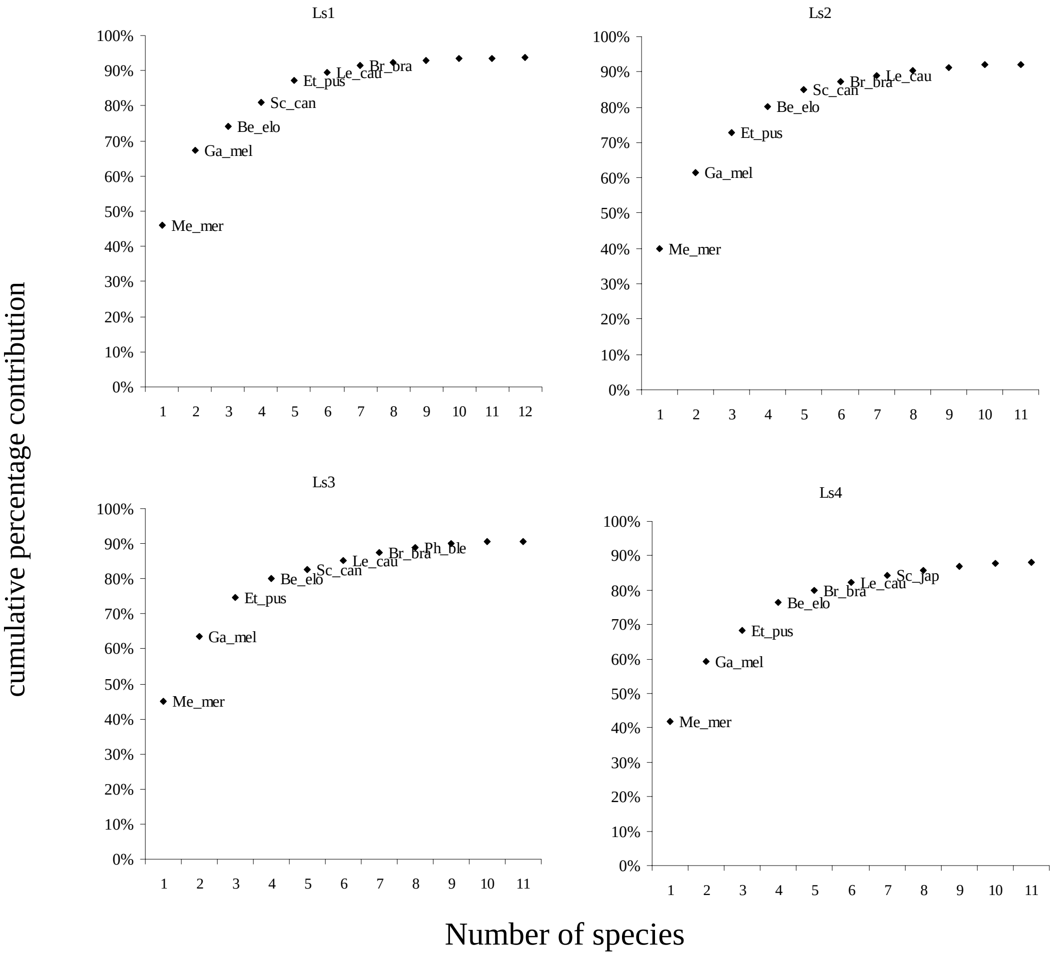

Figure 3.3 Cumulative percentage contribution of caught species by the different hook sizes of semi-pelagic longline. For description of species designations see Table 3.3. The labels of the less important species were removed for clarity.

Elasmobranchs (*Galeus melastomus*, *Etmopterus* sp. and *Scyliorhinus canicula*) were almost exclusively caught by semi-pelagic longline catches, accounting for between 30% and 40% of the total catch in numbers. The trammel nets also caught a small percentage, less than 1% for *S. canicula*, while *G. melastomus and Etmopterus* sp. accounted for 3% of crustacean trawl and fish trawl catches.

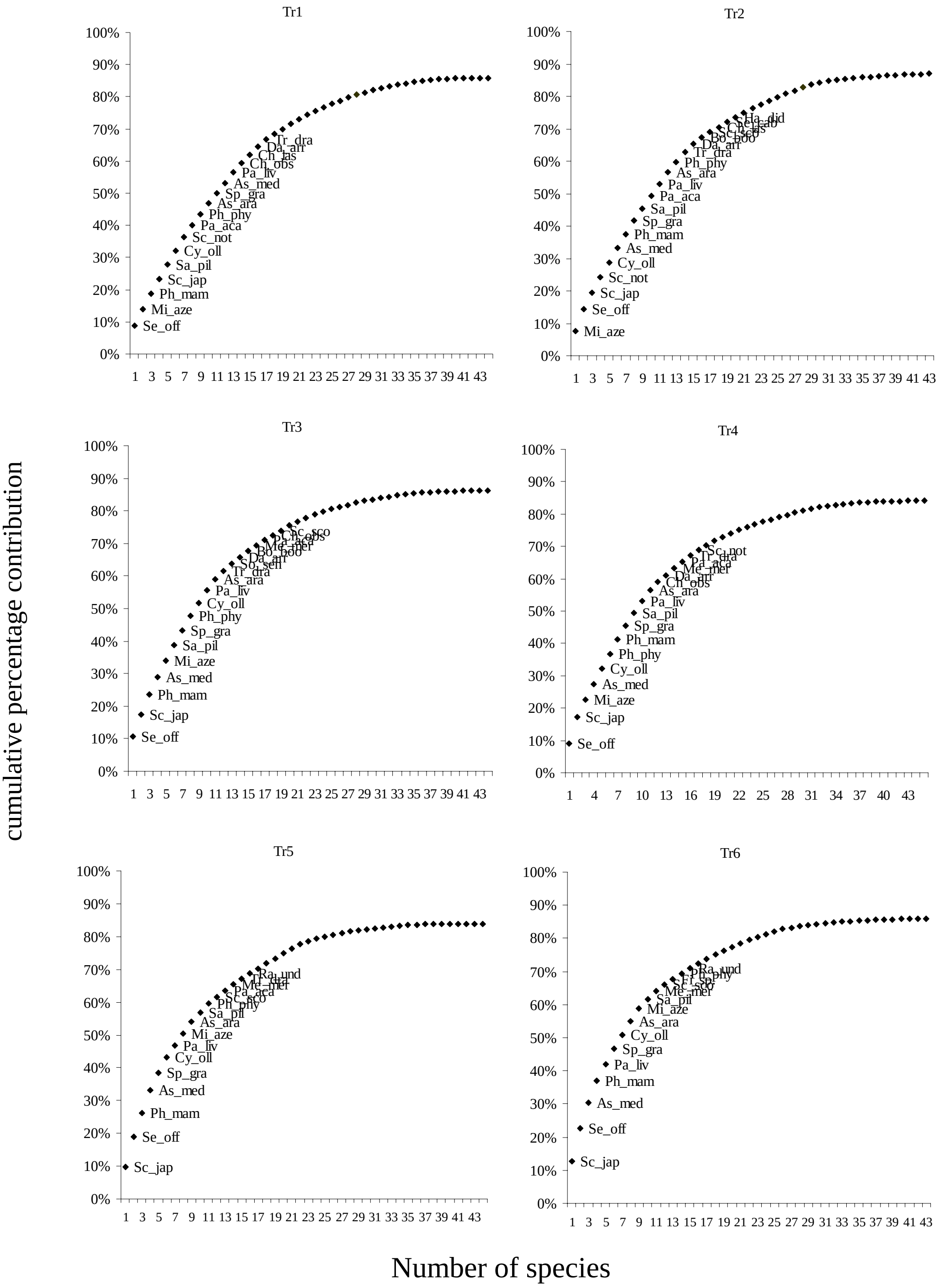

Figure 3.4 Cumulative percentage contribution of caught species by the different mesh sizes combinations of trammel nets. For description of species designations see Table 3.3. The labels of the less important species were removed for clarity.

The cephalopod *Sepia officinalis* was captured mainly with trammel nets, accounting for around 9% of the catch and it accounted for 1% of the gill net catches. This species was almost absent in the catches of the other gears.

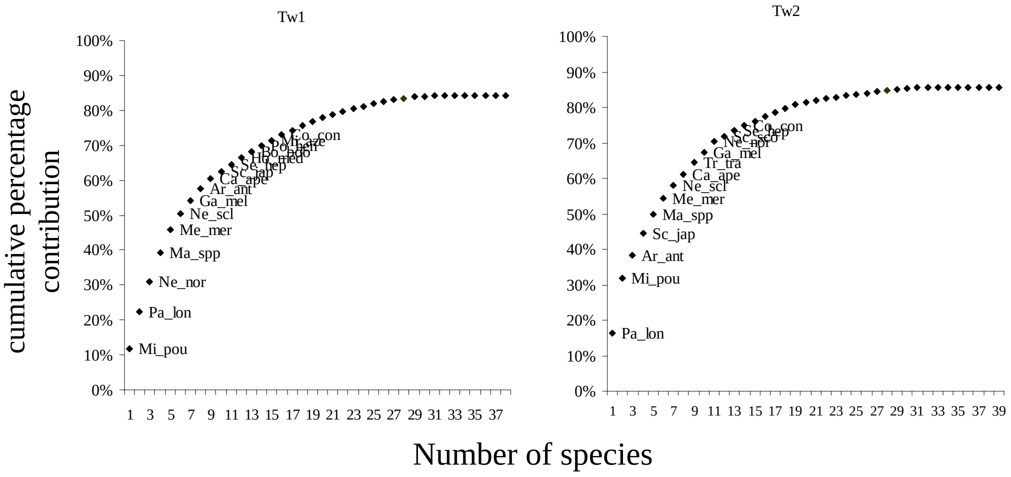

Figure 3.5 Cumulative percentage contribution of caught species by the two different *métiers* of trawls. For description of species designations see Table 3.3. The labels of the less important species were removed for clarity.

Flatfish (*Microchirus azevia*, *Dicologoglossa cuneata*, *Solea senegalensis, Solea vulgaris*) were mostly caught by trammel nets, the combinations with the smaller inner mesh sizes caught 7-10% and the combinations with the largest inner mesh size caught less than 6%; while for gill nets and trawls, these species represent less than 2% of the total catch in numbers.

Mean length, mean trophic level, mean Shannon-Wiener diversity index and mean species richness of the main gears, are represented graphically in Figure 3.6. To calculate these indicators 47 fish species were used.

Pair wise comparisons of the differences between the various gears (Table 3.2) for the mean length of caught fish, indicate that the semi-pelagic longline caught the largest individuals and this was significantly ($p<0.001$) different from all the other gears, while the gill net, bottom longline and crustacean trawl caught significantly ($p<0.001$) smaller individuals than trammel net. Fish trawls caught a wide size range with mean length and were only significantly ($p<0.001$) different from that of semi-pelagic longline, gillnet and crustacean trawl.

Table 3.2 Results of the one way ANOVA and a pair wise comparisons (Tukey HSD) of each main gear types studied for (a) mean length of fish, (b) trophic level of fish, (c) diversity index Shannon-Wiener for fish, (d) number of fish species, (e) mature fish, (f) optimum length and (g) megaspawners.

	Gill net	Bottom longline	Semi-pelagic longline	Trammel net	Crustacean trawl
a) Mean length of catch (cm), one-way ANOVA F= 98.96, *P<0.001*					
Bottom longline	ns				
Semi-pelagic longline	X	X			
Trammel net	X	X	X		
Crustacean trawl	ns	ns	X	X	
Fish trawl	X	ns	X	ns	X
b) Trophic level of fish, one-way ANOVA F= 22.12, *P<0.001*					
Bottom longline	X				
Semi-pelagic longline	X	ns			
Trammel net	X	ns	X		
Crustacean trawl	X	ns	ns	X	
Fish trawl	X	ns	ns	ns	ns
c) Diversity index (H') for fish, one-way ANOVA F=35.43, *P<0.001*					
Bottom longline	ns				
Semi-pelagic longline	X	X			
Trammel net	X	X	X		
Crustacean trawl	X	X	ns	X	
Fish trawl	X	X	ns	X	ns
d) Number of fish species, one-way ANOVA F= 26.38, *P<0.001*					
Bottom longline	ns				
Semi-pelagic longline	X	ns			
Trammel net	X	X	X		
Crustacean trawl	ns	X	X	ns	
Fish trawl	ns	ns	X	X	ns
e) Mature fish, one-way ANOVA F=38.92, *P<0.001*					
Bottom longline	ns				
Semi-pelagic longline	X	X			
Trammel net	X	X	ns		
Crustacean trawl	X	ns	X	X	
Fish trawl	ns	ns	X	X	ns
f) Optimum length fish, one-way ANOVA F=4.05, *P<0.001*					
Bottom longline	ns				
Semi-pelagic longline	ns	ns			
Trammel net	ns	ns	ns		
Crustacean trawl	X	ns	ns	ns	
Fish trawl	ns	ns	ns	ns	ns
g) Megaspawners, one-way ANOVA F=2.74, *P<0.01*					
Bottom longline	ns				
Semi-pelagic longline	ns	ns			
Trammel net	ns	ns	ns		
Crustacean trawl	ns	ns	ns	ns	
Fish trawl	ns	ns	ns	ns	ns

ns, not significant

The mean trophic levels of the gill net catches was significantly (p<0.001) lower than all the other gears. Each of the other gears had higher trophic levels due to the presence of more predators in their catches. Trammel nets had significantly (p<0.001) lower trophic levels than crustacean trawl and semi-pelagic longlines.

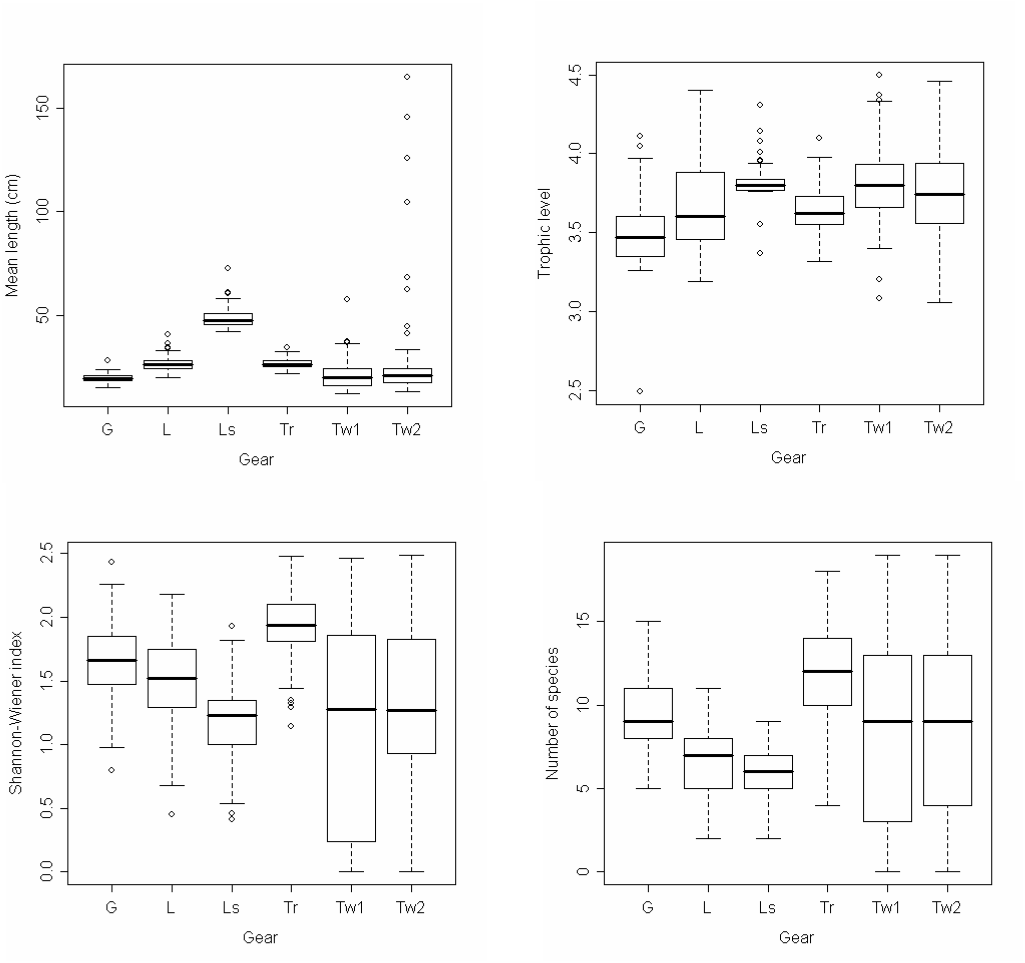

Figure 3.6 Boxplots of mean length, mean trophic level, mean Shannon-Wiener diversity index and mean number of species of fish caught by each of the six main gear types. Bars are standard deviations. Table 3.2 presents the statistical analysis of the gear comparisons. (G: gill net; L: bottom longline; Ls: semi-pelagic longline; Tr: trammel net; Tw1: crustacean trawl; Tw2: fish trawl).

Trammel nets caught the highest number of fish species and were significantly (p<0.001) different from the other gears with the exception of crustacean trawls. The semi-pelagic longline caught significantly (p<0.001) fewer fish species than the other gears with the exception of the bottom longline. The semi-pelagic longline and both trawls had a significantly (p<0.001) lower diversity of fish in the catch than the other gears, but were not different between themselves. Trammel nets had a significantly (*p*<0.001) higher fish diversity index than all other gears. Between all main gear types, the contribution of the non fish species was not significant with the exception of the trammel net (*t*=-13.04; *p*<0.001).

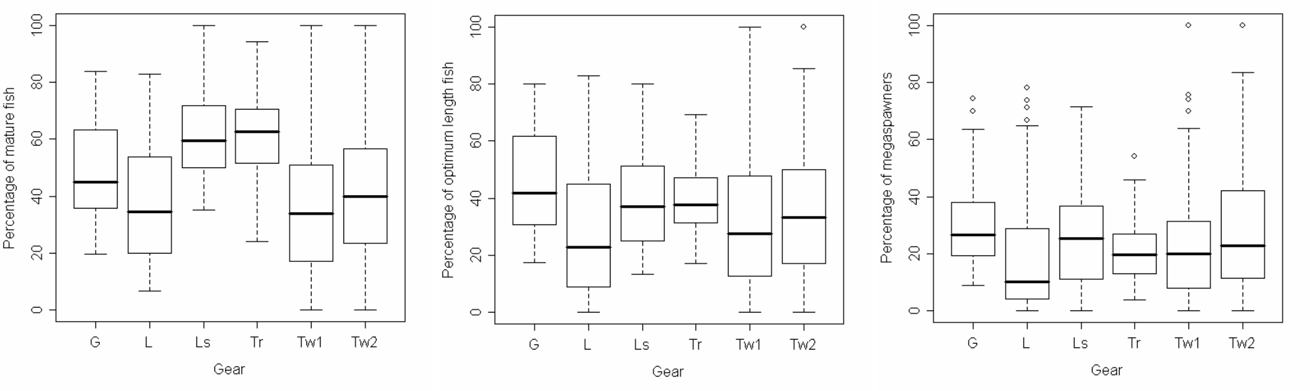

Figure 3.7 Boxplots of percentage of Mature fish, Optimum length fish and Megaspawners by each of the six main gear types. Bars are standard deviations. Table 3.2 presents the statistical analysis of the gear comparisons. (G: gill net; L: bottom longline; Ls: semi-pelagic longline; Tr: trammel net; Tw1: crustacean trawl; Tw2: fish trawl).

The comparison of the indicators Mature, Optimum size and Megaspawners (Figure 3.7) shows that trammel nets and semi-pelagic catches had significantly (*p*<0.001) higher relative abundances of mature fish in the catch than all other gears, but were not different between themselves. Gill net catches had significantly higher relative abundances of mature and optimum sized fish than crustacean trawl catches. There were no significant differences in the megaspawners relative abundance between all gears.

The results of one way analysis of variance comparing fish catch indicators across the different gear sizes indicates that the mean length of fish caught differed significantly within some gear types (Figure 3.8). The gill net with the smallest mesh sizes (G1, G2) had significantly lower mean length of fish caught than the largest mesh size (G4) (F=22.5; *p*<0.001). The same occurred with the bottom longline where the larger hook sizes (L1, L2) attracted significantly larger fish than the smallest hook size (L4) (F=11.05; *p*<0.001). For the semi-pelagic longline there were no significant relationships between the mean length of caught fish and hook size (F=0.3; p>0.5). In the case of the trammel net, there were significant differences between the mean length of fish caught with different inner panel mesh sizes as the smaller inner mesh combinations (Tr1, Tr2) caught significantly smaller fish (F=26.98; $p<0.001$) than the other mesh combinations. No significant relationships were found within each gear type for trophic level ($p>0.001$).

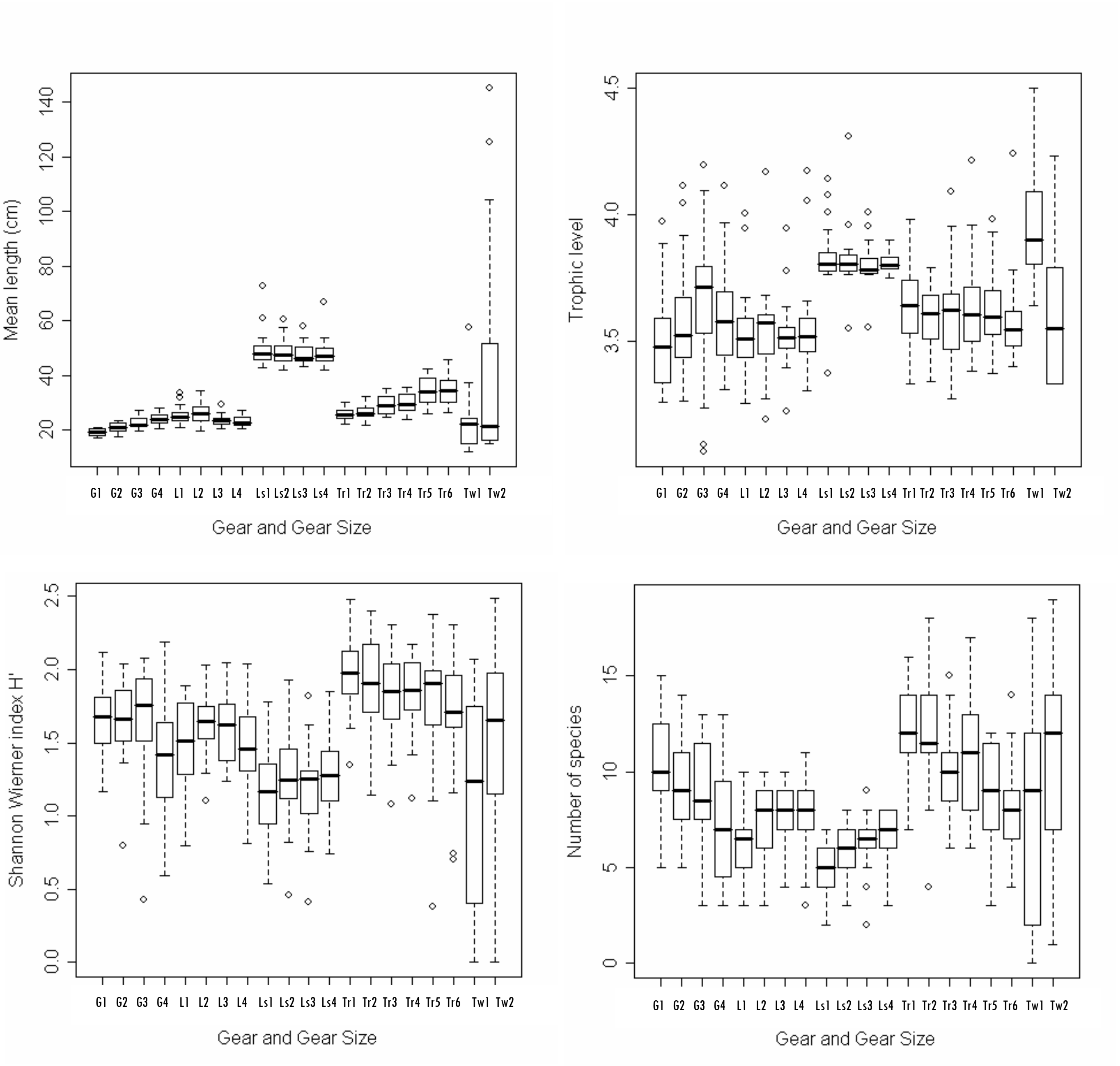

Figure 3.8 Boxplots of mean length, mean trophic level, mean Shannon-Wiener diversity index and mean number of species of fish caught by each size of the six gear types. Bars are standard deviations. (G: gill net; L: bottom longline; Ls: semi-pelagic longline; Tr: trammel net; Tw1: crustacean trawl; Tw2: fish trawl; for description of gear sizes see Table 2.1).

The diversity index was significantly greater (F=8.2; *p*<0.001) in smaller mesh sizes of gill net (G1, G2) and significantly more species (F=10.4; *p*<0.001) were caught with these. A significantly greater (F=11.01; *p*<0.001) number of species were captured with the smaller trammel net inner mesh size combination (Tr1, Tr2) than with the larger ones (Tr5, Tr6). For the diversity index these mesh combinations (Tr1, Tr2) were also significantly different (F=5.15; *p*<0.001) from the larger mesh combination (Tr6).

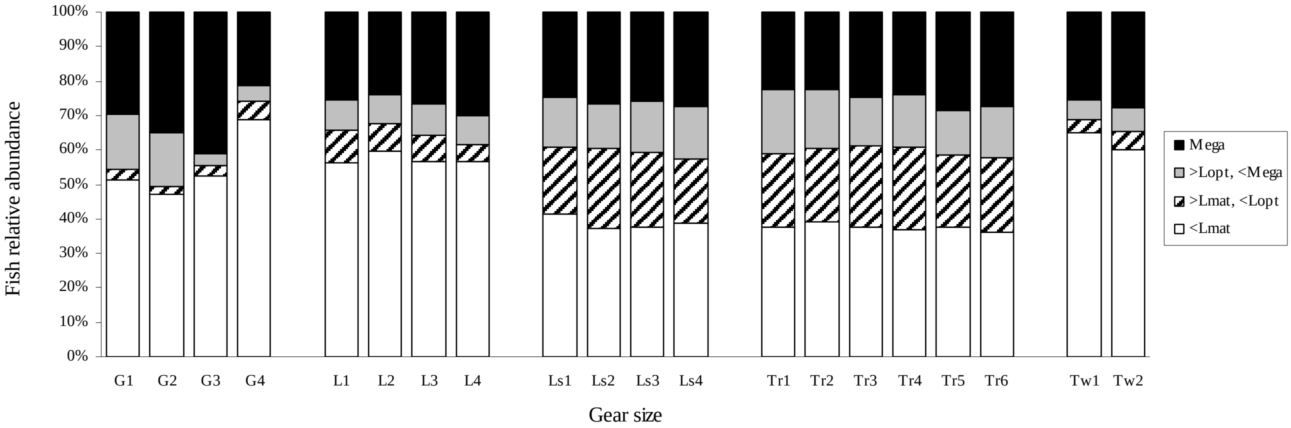

Figure 3.9 Relative abundance of immature, mature, optimum length and megaspawners for each gear size (G: gill net; L: bottom longline; Ls: semi-pelagic longline; Tr: trammel net; Tw1: crustacean trawl; Tw2: fish trawl; for description of gear sizes see Table 2.1).

A significant difference between gear sizes for the relative abundance of mature fish, optimum length fish and megaspawners in the catches (Figure 3.9) was found only for gill nets. The largest mesh size (G4) had significantly (F=7.10; *p*<0.001) lower relative abundance of mature and optimum length fish in the catch. Megaspawners relative abundance was only significantly different (F=7.01; *p*<0.001) between the two larger mesh sizes, the largest mesh size (G4) caught fewer megaspawners than a smaller mesh size (G3).

Table 3.3 Most abundant invertebrate and fish species caught by the gill nets, longlines, trammel nets and trawls.

ascidian		**Species Code**	**echinoderm**		**Species code**
Ascidiidae	*Phallusia mammillata*	Ph_mam	Astropectinidae	*Astropecten aranciacus*	As_ara
cephalopode			Echinidae	*Paracentrotus lividus*	Pa_liv
Loliginidae	*Alloteuthis subulata*	Al_sub	Gorgonocephalidae	*Astropartus mediterraneus*	As_med
Sepiidae	*Sepia officinalis*	Se_off	Spatangidae	*Echinocardium cordatum*	Ec_cor
crustaceans			Toxopneustidae	*Sphaerechinus granularis*	Sp_gra
Diogenidae	*Dardanus arrosor*	Da_arr	**gastropode**		
Portunidae	*Polybius henslowi*	Po_hen	Turbinidae	*Astraea rugosa*	As_rug
Aristeidae	*Aristeus antennatus*	Ar_ant	Volutidae	*Cymbium olla*	Cy_oll
Penaeidae	*Parapenaeus longirostris*	Pa_lon	**polychaeta**		
Nephropidae	*Nephrops norvegicus*	Ne_nor	Serpulidae	*Filograna* sp.	Fi_sp
fish					
Batrachoidae	*Halobatrachus didactylus*	Ha_did			
Bramidae	*Brama brama*	Br_bra			
Caproidae	*Capros aper*	Ca_ape			
Carangidae	*Trachurus trachurus*	Tr_tra	**fish**		
Centracanthidae	*Spicara maena*	Sp_mae	Serranidae	*Serranus cabrilla*	Se_cab
Centriscidae	*Macroramphosus* spp.	Ma_spp		*Serranus hepatus*	Se_hep
Citharidae	*Citharus linguatula*	Ci_lin	Soleidae	*Dicologoglossa cuneata*	Di_cun
Clupeidae	*Sardina pilchardus*	Sa_pil		*Microchirus azevia*	Mi_aze
Congridae	*Conger conger*	Co_con		*Solea senegalensis*	So_sen
Dalatiidae	*Etmopterus pusillus*	Et_pus		*Solea vulgaris*	So_vul
	Etmopterus spinax	Et_spi	Sparidae	*Boops boops*	Bo_boo
Gadidae	*Gadiculus argenteus*	Ga_arg		*Diplodus bellottii*	Di_bel
	Micromesistius poutassou	Mi_pou		*Diplodus sargus*	Di_sar
Macrouridae	*Nezumia sclerorhynchus*	Ne_scl		*Diplodus vulgaris*	Di_vul
Merluccidae	*Merluccius merluccius*	Me_mer		*Lithognathus mormyrus*	Li_mor
Mugilidae	*Liza aurata*	Li_aur		*Pagellus acarne*	Pa_aca
Mullidae	*Mullus surmuletus*	Mu_sur		*Pagellus erythrinus*	Pa_ery
Phycidae	*Phycis blennoides*	Ph_ble		*Pagrus pagrus*	Pa_pag
	Phycis phycis	Ph_phy		*Spondyliosoma cantharus*	Sp_can
Rajidae	*Raja undulata*	Ra_und	Trachichthyidae	*Hoplostethus mediterraneus*	Ho_med
Scombridae	*Scomber japonicus*	Sc_jap	Trachinidae	*Trachinus draco*	Tr_dra
	Scomber scombrus	Sc_sco	Trichiuridae	*Benthodesmus elongatus*	Be_elo
Scorpaenidae	*Scorpaena notata*	Sc_not		*Lepidopus caudatus*	Le_cau
			Triglidae	*Chelidonichthys lastoviza*	Ch_las
Scyliorhinidae	*Galeus melastomus*	Ga_mel		*Chelidonichthys obscurus*	Ch_obs
	Scyliorhinus canicula	Sc_can		*Lepidotrigla cavillone*	Le_cav

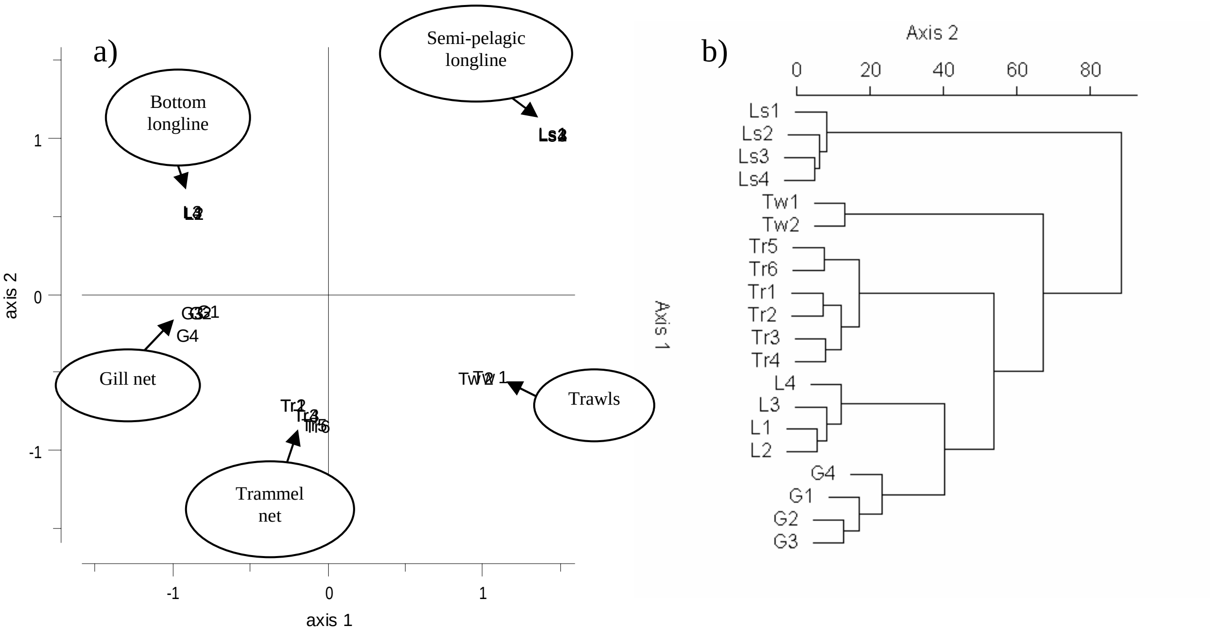

Figure 3.10 a) Multidimensional scaling plot and b) clustering based on Bray-Curtis for fish catch in the 20 fishing gear and mesh or hook size categories.

For the MDS plot (Figure 3.10a) the stress value was 0.0057, which indicated a very good ordination, with groups being established according to the different fishing gears. Semi-pelagic longline fish catches were very dissimilar from the others. Gill nets and bottom longlines had the most similar fish catch composition. Within gears, dissimilarity in catch composition between the largest gill net mesh size and the other gill net mesh sizes can be seen.

The results of the classification based on the dissimilarity matrix gave the same number of groups as the number of main gear types. The plot of the cluster analysis for the whole fish catch (Figure 3.10b) shows segregation between main gears, with the semi-pelagic longline fishery being highly defined and clearly separated from the other gears. Trawl catches were the next group to be distinguished from the others, while gill net, bottom longline and trammel were the less dissimilar groups in terms of fish catch composition. Only at a dissimilarity level of 30% it is possible to identify the 5 groups that correspond to the 5 main gear types. For trammel nets, the combinations with the same inner mesh size (Tr1-2; Tr3-4; Tr5-6) grouped together. For gill nets, the larger (G4) mesh size was the most differentiated from the others.

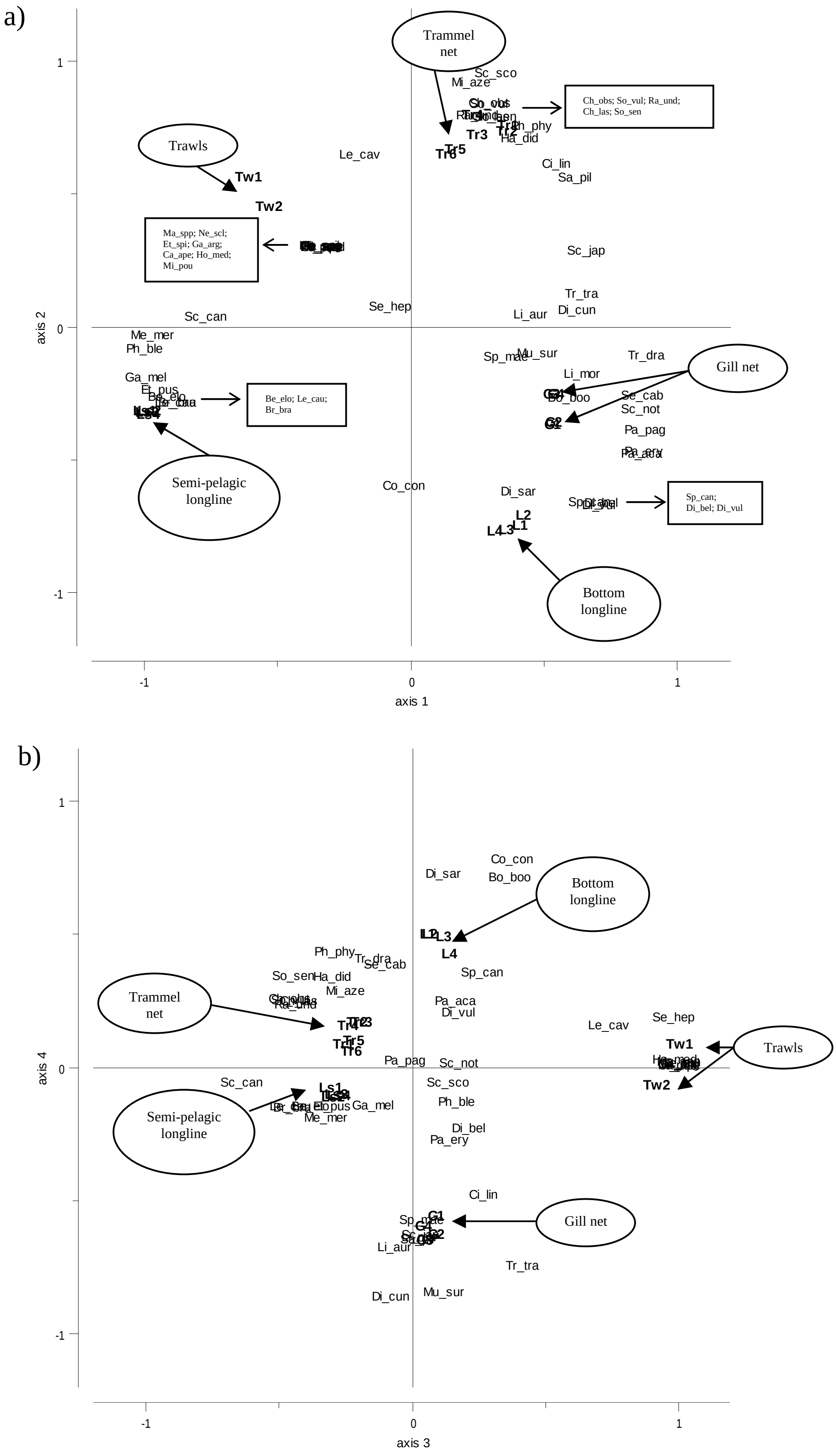

Figure 3.11 Plot of variables (species) of the PCA on the matrix of the gear sizes for 47 species of fish. Representation of active categories on the a) first two factorial axes, b) third and fourth factorial axes. This shows the relationships between the species and the fishing gear (bold). See Table 3.2 for description of species and for description of gear sizes see Table 2.1.

The first PCA analysing the relative abundance of the species averaged for each gear size (20 cases and 47 variables) (Figure 3.11) showed that the first four principal components explained more than 90% of the observed variance. The first two axes explained 35.5% and 22.5%, respectively, of the total variance. The first axis was drawn by the contrast between deep and shallow water fisheries with trawl and semi-pelagic longline fisheries at the deeper end and the remaining gear types at the shallower end. This axis also points out the distinction of elasmobranchs (*Etmopterus pusillus*, *Galeus melastomus*, *Scyliorhinus canicula*) and gadoids (*Merluccius merluccius*, *Phycis blennoides*) at the deeper end and the sparids at the other end, where *Diplodus bellotii, Diplodus vulgaris, Pagellus erythrinus, Pagellus acarne, Spondyliosoma cantharus* are some examples of the most abundant species. The second axis shows a distinction between bottom longlines and gill net (that attract more benthopelagic species as sparids) with trammel nets (that target mainly flatfish and other bottom species). The third axis indicates difference in crustacean trawl and fish trawl in the fish species dominance with the remaining gears and the fourth axis highlights the distinction between gill net and longline fisheries where the species that occupy the centre of the PCA plot show a close correlation to both gears.

The results of the one way ANOSIM analysis performed on the fish catch composition of each main gear (gill net, bottom and semi-pelagic longlines, trammel net and trawls) showed that trammel nets were more significantly different from gill net and both longlines ($p<0.005$) than from trawls ($p<0.05$). The assemblage composition of catches differed also for gill nets and longlines ($p<0.05$) and between bottom and semi-pelagic longlines ($p<0.05$).

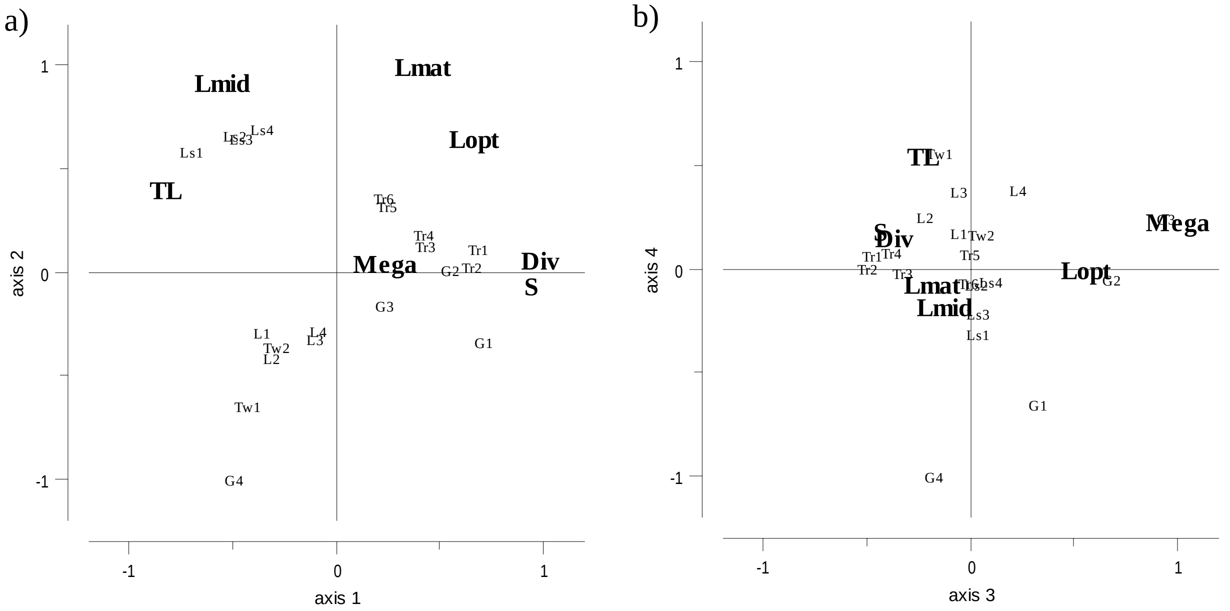

Figure 3.12 PCA plot of indicators on the matrix of the gear sizes. Representation of active categories on the a) first two factorial axes, b) third and fourth factorial axes. This shows the relationships between the indicators (bold) and the fishing gear. For description of indicators see Table 2.2 and for description of gear sizes see Table 2.1.

The indicators were averaged for each gear size (20 cases and 7 variables) (Figure 3.12). The first and the second axes explained 40% and 28%, respectively, of the total variance. The first axis of the PCA points to the contrast in terms of Trophic level and Species diversity and Richness of the fish caught, with semi-pelagic longline catches represented by higher trophic levels and lower species diversity or richness than the trammel net or gill net catches. The second axis highlights the contrast in terms of Mean length, Mature and Optimum sized fish, with semi-pelagic longline and trammel nets catches with a higher proportion of larger, mature and optimum sized fish, while bottom longlines, crustacean trawl, fish trawl and the largest mesh size of gill nets have the opposite pattern (smaller and more immature fish). The third axis highlights the Megaspawner indicator with the intermediate mesh sizes of gill net represented by more megaspawners than the largest mesh size of gill net and all combinations of trammel nets, while the remaining gears have intermediate values.

Redundancy of the studied indicators was observed with Species diversity and Richness indicators as they grouped in similar regions of the multivariate space.

The mean sizes in the catch, the length at maturity, optimum size for catch and megaspawners size were plotted for the most important species. The minimum legal size is indicated when available (Figure 3.13 to Figure 3.19) and the values of these indicators are given in Table 3.4 and Table 3.5.

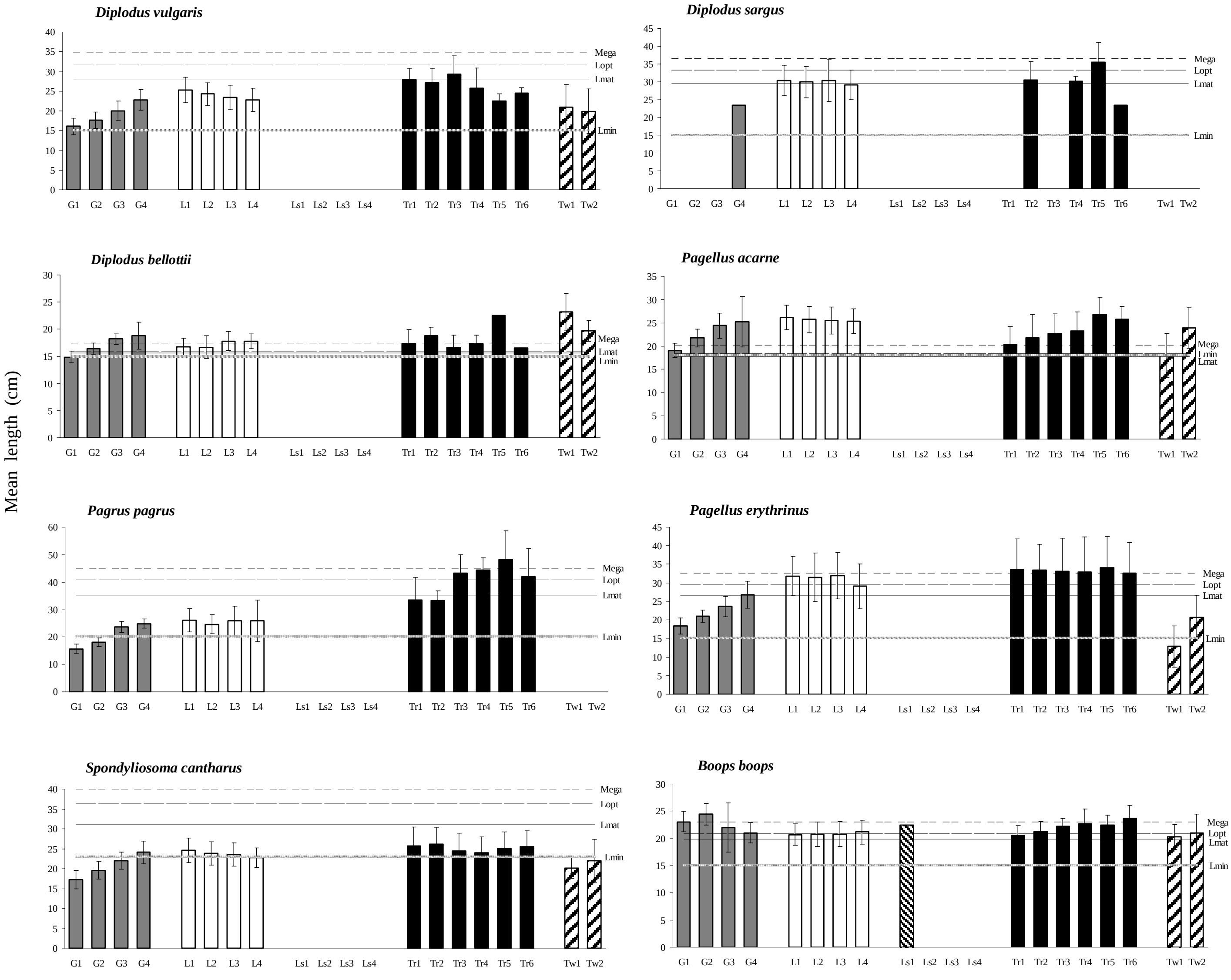

Figure 3.13 Mean length at catch, length at maturity, optimum length, megaspawners length and minimum legal size of *Diplodus vulgaris, D. bellottii, D. sargus, Pagellus acarne, P. erythrinus, Pagrus pagrus, Spondyliosma cantharus and Boops boops*.

Legend: —— Lmat — – – Lopt – – – – Mega ▬ Lmin

Mean length at catch was above mature and megaspawners size for the majority of the gears categories for only two seabreams, *D. bellottii*, and *P. acarne*. The mean size of both species increased with the mesh size for gill net. High percentages of megaspawners were captured with the exception of the smaller mesh size of gill net, where immature specimens were more common.

The white seabream (*D. sargus*) was mainly captured by all hook sizes of bottom longline around the mature stage. The catch of immature specimens was highest with the smallest hook. Immature common two banded seabream (*D. vulgaris*) were caught by gill nets, bottom longlines and both trawls. Trammel nets, with most meshes combinations, had the lowest percentages of immature specimens (Figure 3.13 and Tables 3.4 and 3.5).

Pagellus erythrinus mean length was above the minimum legal size for all gears except the crustacean trawl. Only for bottom longlines and trammel nets was the mean length above optimum size and with very high percentages of megaspawners. Gill nets captured mainly immature individuals of this species, especially with the smaller meshes. Immature black seabream (*S. cantharus*) were caught with all gears and only trammel nets, bottom longlines and the largest mesh of gill net caught legal sized individuals.

Immature red seabream (*P. pagrus*) were caught with gill nets and bottom longline but were mostly greater than the minimum legal size, while the trammel net, with the larger inner meshes, caught mainly mature individuals. Bogue (*B. boops*) was caught with a mean length higher than mature size and quite often with optimum length and very high percentages of megaspawners (Figure 3.13 and Tables 3.4 and 3.5).

Immature scorpionfish (*S. notata*) were caught mostly by trawls, bottom longlines and the smallest mesh size of gill nets, while trammel nets caught generally mature individuals with high percentages of megaspawners (Figure 3.14 and Tables 3.4 and 3.5).

Megaspawner size sardines (*S. pilchardus*) were caught with all nets, while immature horse mackerel (*T. trachurus*) but above minimum legal size were caught by gill nets, trawls and trammel nets. A small percentage of mature individuals was also captured by bottom longlines. For greater weever (*T. draco*) the catches were made up mostly of immature fish for all gears but no minimum legal size is available (Figure 3.14 and Tables 3.4 and 3.5).

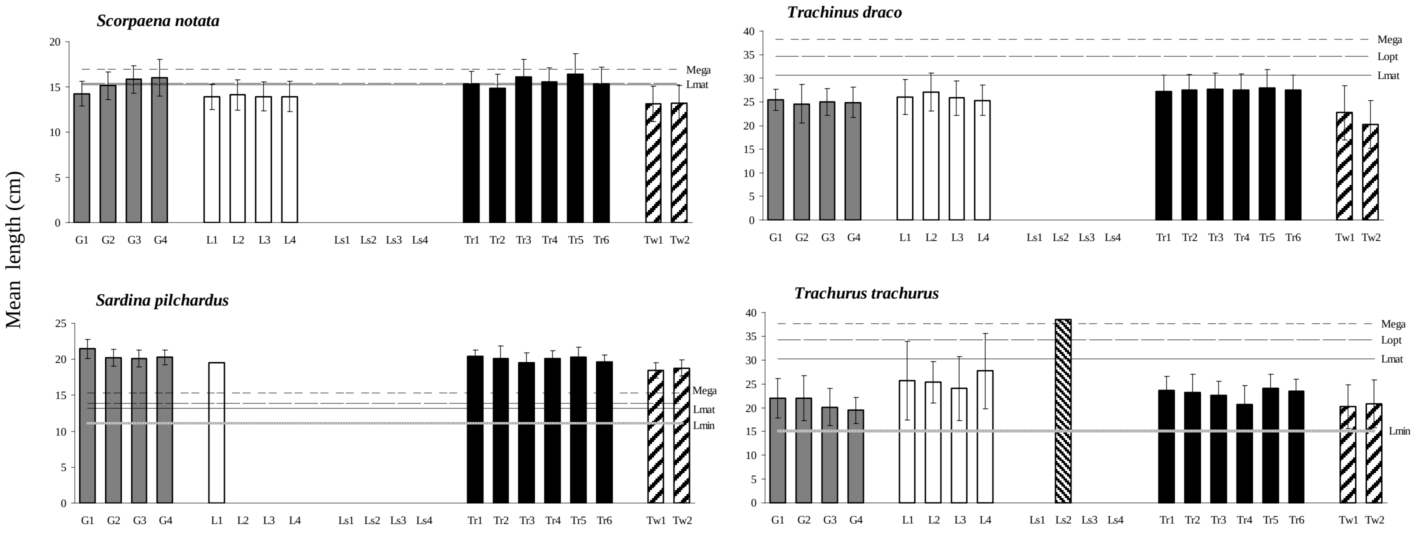

Figure 3.14 Mean length at catch, length at maturity, optimum length and megaspawners length of *Scorpaena notata, Trachinus draco* plus minimum legal size for *Sardina plichardus and Trachurus trachurus*.

Legend: ——— Lmat   — — – Lopt   – – – – Mega   ━━━ Lmin

The chub mackerel (*S. japonicus*) mean length in all catches was above the minimum legal size, but below length at maturity. For the semi-pelagic longline, trammel net and crustacean trawl the mean length was very close to the mature length, with very low or null percentages of fish with optimum length or megaspawners. The exception was the fish trawl with a high percentage of megaspawners, but a very wide range of sizes. Gill net and bottom longline gears captured mostly immature individuals (Figure 3.15 and Tables 3.4 and 3.5).

The elongate frostfish (*B. elongatus*) caught by semi-pelagic longlines and trawls were mainly of megaspawner size. The snipefish (*Macroramphosus* sp.) was captured around maturity size. Most *P. phycis* caught by gill nets were immature, while trawls and trammel nets captured a small percentage of mature individuals, including megaspawners. The bottom longline had higher percentages of mature individuals than the other gears but no megaspawners. The red mullet (*M. surmuletus*) was captured mostly with megaspawner size, while blue whiting (*M. poutassou*) of megaspawner size were caught with semi-pelagic longlines. More than 60% of the catch of this species by trawls was immature, while about 20% were megaspawners (Figure 3.15 and Tables 3.4 and 3.5).

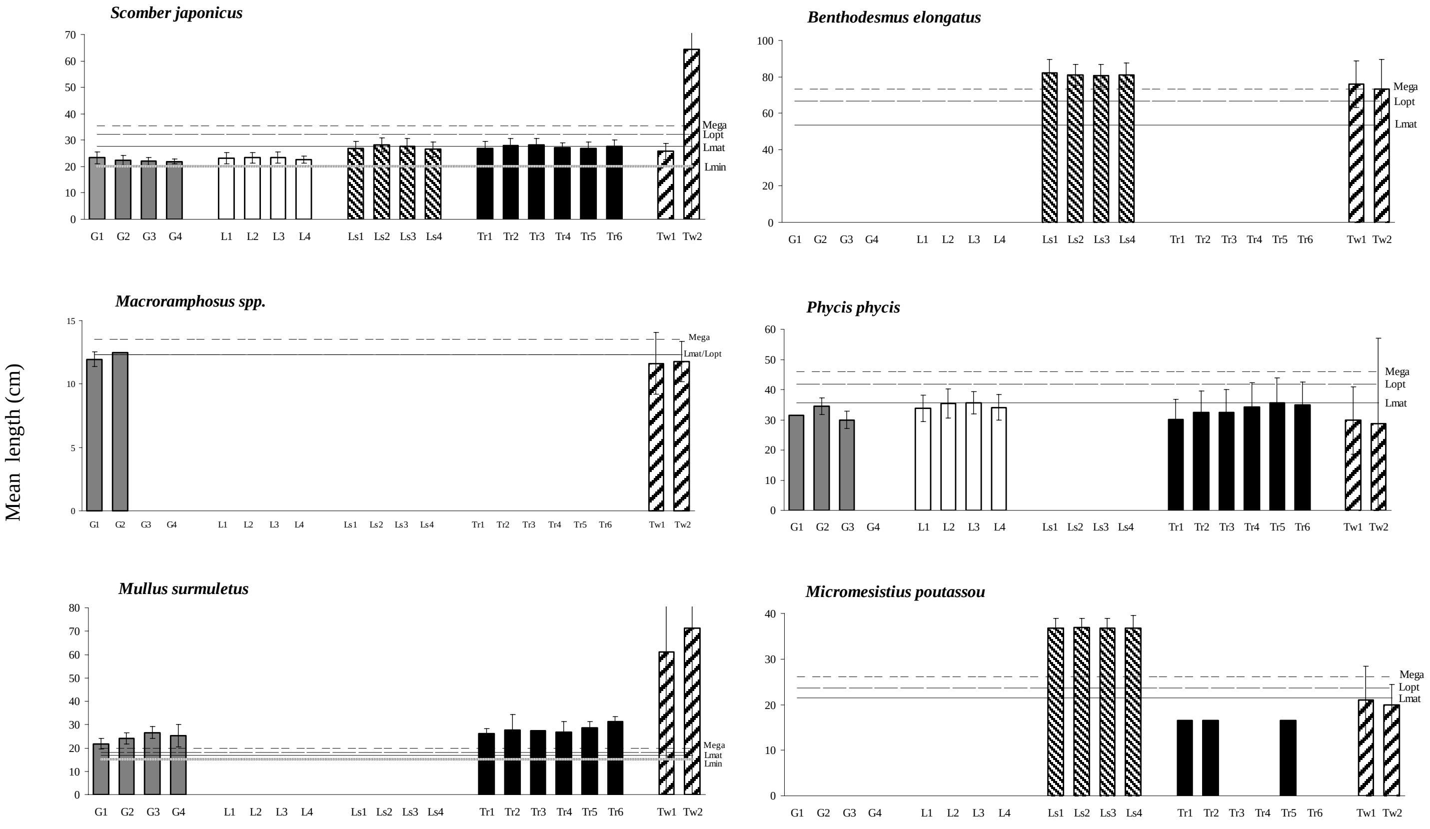

Figure 3.15 Mean length at catch, length at maturity, optimum length and megaspawners length of *Benthodesmus elongates*, *Macroramphosus* sp., *Phycis phycis,* and *Micromesistiou poutassou* plus minimum legal size for *Scomber japonicus* and *Mullus surmuletus.*

Legend: ——— Lmat —– – – Lopt – – – – Mega ▬▬ Lmin

Trawls caught immature flatfish, *M. azevia*, while trammel nets captured mostly mature individuals with values of megaspawners around 30%. Trammel nets mainly caught mature *S. senegalensis* with higher percentages of mature fish and megaspawners in the larger inner mesh size combinations (Figure 3.16 and Tables 3.4 and 3.5).

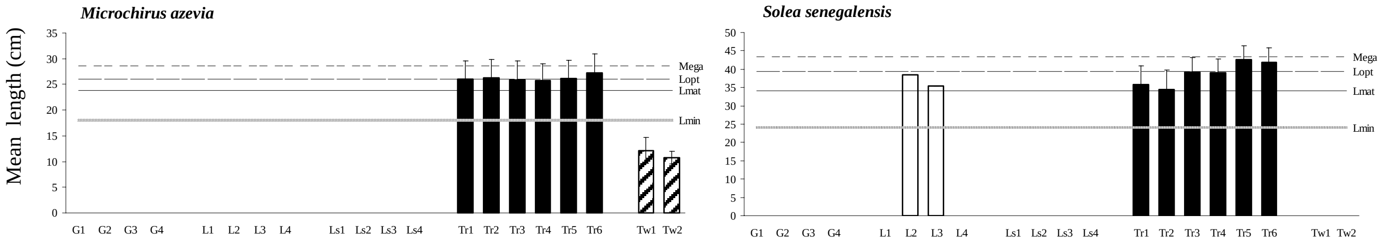

Figure 3.16 Mean length at catch, length at maturity, optimum length, megaspawners length and minimum legal size of *Microchirus azevia*, *Solea senegalensis*.

Legend: ——— Lmat — – – Lopt – – – – Mega ━━━ Lmin

The conger (*Conger conger*) was captured mostly immature and below minimum legal size in bottom longline and both trawls (Figure 3.17 and Tables 3.4 and 3.5). The cuttlefish (*Sepia officinalis*) was caught above minimum legal size with gill nets and trammel nets, while trawls caught undersized individuals (Figure 3.17 and Tables 3.4 and 3.5).

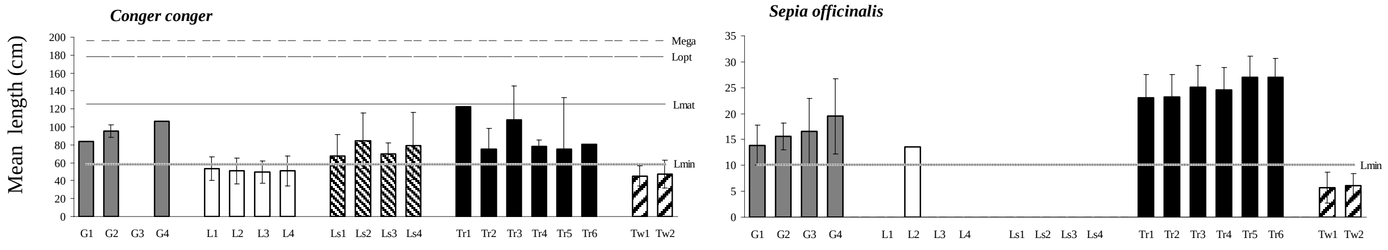

Figure 3.17 Mean length at catch, length at maturity, optimum length, megaspawners length and minimum legal size of *Conger conger* and *Sepia officinalis*.

Legend: ——— Lmat — – – Lopt – – – – Mega ━━━ Lmin

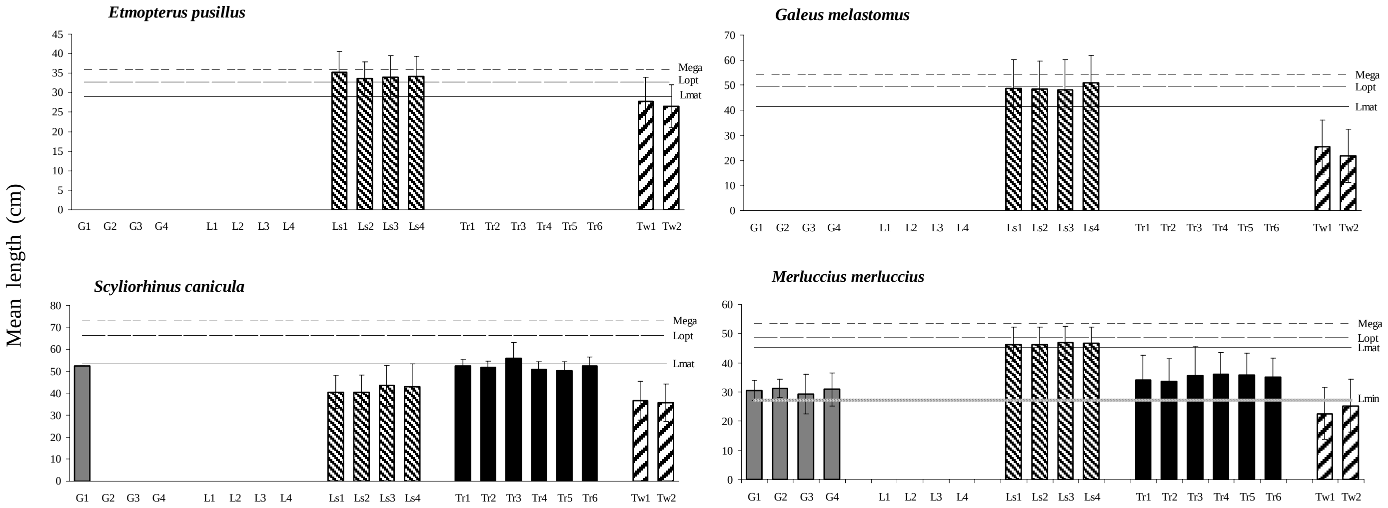

Figure 3.18 Mean length at catch, length at maturity, optimum length and megaspawners length of *Etmopterus pusillus, Galeus melastomus* plus minimum legal size for *Scyliorhinus canicula* and *Merluccius merluccius*.

Legend: ——— Lmat — – – Lopt – – – – Mega ═══ Lmin

The elasmobranchs, *E. pusillus, G. melastomus* caught by trawls were mostly immature, while semi-pelagic longlines caught mostly mature individuals, with values of megaspawners between 40%-60%. More than 75% of the elasmobranch *S. canicula* captured with semi-pelagic longlines, trawls and some combinations of trammel nets were immature. Trammel nets captured the highest percentages of mature individuals but rarely captured megaspawners (Figure 3.18 and Tables 3.4 and 3.5).

Immature hake (*M. merluccius*) were caught with gill nets, trammel nets and trawls and mean length at catch was above minimum legal size for gill nets and trammel nets while trawls caught mostly undersized hake. All hook sizes of semi-pelagic longline caught around 50% of mature hake of which 10% were megaspawners (Figure 3.18 and Tables 3.4 and 3.5).

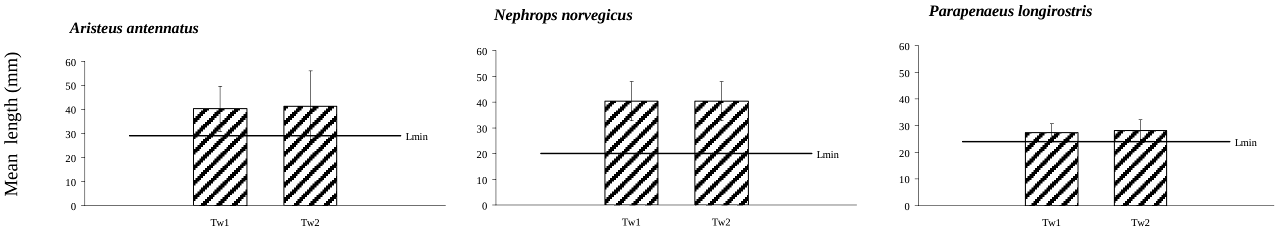

Figure 3.19 Mean length of carapace at catch and minimum legal size of carapace of *A. antenatus*, *N. norvegicus* and *P. longirostris.*

The crustaceans targeted by trawls were always caught with mean length above minimum legal size (Figure 3.19).

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Table 3.4 Indicators (length at maturity, optimum length and megaspawners) of the most important species in number for each gear size of gill net, bottom longline and semi-pelagic longline.

		species	*Benthodesmus elongatus*	*Boops boops*	*Conger conger*	*Diplodus bellottii*	*Diplodus sargus*	*Diplodus vulgaris*	*Etmopterus pusillus*	*Galeus melastomus*	*Macroramphosus spp.*	*Merluccius merluccius*	*Microchirus azevia*	*Micromesistius poutassou*	*Mullus surmuletus*	*Pagellus acarne*	*Pagellus erythrinus*	*Pagrus pagrus*	*Phycis phycis*	*Sardina pilchardus*	*Scomber japonicus*	*Scorpaena notata*	*Scyliorhinus canicula*	*Solea senegalensis*	*Spondyliosoma cantharus*	*Trachinus draco*	*Trachurus trachurus*
Gear	Gear size	Indicator																									
Gill net	G1	<Lmat		1%	100%	61%		100%			60%	100%			0%	3%	100%	100%	100%	0%	90%	71%	100%		100%	99%	93%
		>Lmat		99%	0%	39%		0%			40%	0%			100%	97%	0%	0%	0%	100%	10%	29%	0%		0%	1%	7%
		%>Lmat, <Lopt		1%	0%	0%		0%			0%	0%			1%	16%	0%	0%	0%	0%	10%	0%	0%		0%	1%	4%
		%>Lopt, <Mega		13%	0%	38%		0%			37%	0%			5%	63%	0%	0%	0%	0%	0%	18%	0%		0%	0%	2%
		% Mega		85%	0%	1%		0%			4%	0%			94%	17%	0%	0%	0%	100%	0%	12%	0%		0%	0%	0%
	G2	<Lmat		0%	100%	4%		100%			0%	100%			0%	1%	99%	100%	50%	0%	93%	52%			100%	100%	82%
		>Lmat		100%	0%	96%		0%			100%	0%			100%	99%	1%	0%	50%	100%	7%	48%			0%	0%	18%
		%>Lmat, <Lopt		1%	0%	0%		0%			0%	0%			0%	0%	1%	0%	50%	0%	7%	0%			0%	0%	17%
		%>Lopt, <Mega		0%	0%	65%		0%			100%	0%			1%	20%	0%	0%	0%	0%	0%	24%			0%	0%	1%
		% Mega		99%	0%	31%		0%			0%	0%			99%	79%	0%	0%	0%	100%	0%	24%			0%	0%	0%
	G3	<Lmat		15%		0%		99%				100%			0%	3%	92%	100%	100%	0%	98%	15%			100%	94%	89%
		>Lmat		85%		100%		1%				0%			100%	97%	8%	0%	0%	100%	2%	85%			0%	6%	11%
		%>Lmat, <Lopt		0%		0%		1%				0%			0%	0%	5%	0%	0%	0%	2%	0%			0%	6%	5%
		%>Lopt, <Mega		45%		7%		0%				0%			0%	2%	2%	0%	0%	0%	0%	30%			0%	0%	4%
		% Mega		41%		93%		0%				0%			100%	95%	1%	0%	0%	100%	0%	55%			0%	0%	2%
	G4	<Lmat		8%	100%	7%	100%	95%				100%			0%	13%	64%	100%		0%	99%	26%			99%	95%	97%
		>Lmat		92%	0%	93%	0%	5%				0%			100%	87%	36%	0%		100%	1%	74%			1%	5%	3%
		%>Lmat, <Lopt		0%	0%	0%	0%	2%				0%			0%	2%	25%	0%		0%	1%	0%			1%	5%	1%
		%>Lopt, <Mega		50%	0%	6%	0%	3%				0%			9%	11%	8%	0%		0%	0%	44%			0%	0%	0%
		% Mega		42%	0%	87%	0%	0%				0%			91%	75%	2%	0%		100%	0%	29%			0%	0%	1%
Bottom longline	L1	<Lmat		19%	100%	13%	30%	81%								0%	10%	98%	53%	0%	94%	82%			98%	86%	56%
		>Lmat		81%	0%	87%	70%	19%								100%	90%	2%	47%	100%	6%	18%			2%	14%	44%
		%>Lmat, <Lopt		7%	0%	0%	42%	13%								0%	30%	2%	47%	0%	6%	0%			2%	14%	11%
		%>Lopt, <Mega		47%	0%	40%	13%	3%								1%	17%	0%	0%	0%	0%	9%			0%	0%	33%
		% Mega		28%	0%	47%	15%	2%								99%	43%	0%	0%	100%	0%	9%			0%	0%	0%
	L2	<Lmat		19%	100%	21%	44%	86%								0%	26%	95%	37%		98%	71%		0%	98%	77%	89%
		>Lmat		81%	0%	79%	56%	14%								100%	74%	5%	63%		2%	29%		100%	2%	23%	11%
		%>Lmat, <Lopt		12%	0%	0%	30%	11%								0%	15%	5%	51%		2%	0%		100%	2%	20%	11%
		%>Lopt, <Mega		41%	0%	40%	9%	3%								2%	13%	0%	13%		0%	12%		0%	0%	3%	0%
		% Mega		29%	0%	38%	18%	0%								98%	45%	0%	0%		0%	17%		0%	0%	0%	0%
	L3	<Lmat		20%	100%	5%	40%	88%								3%	22%	97%	33%		94%	74%		0%	98%	61%	78%
		>Lmat		80%	0%	95%	60%	12%								97%	78%	3%	67%		6%	26%		100%	2%	39%	22%
		%>Lmat, <Lopt		16%	0%	0%	23%	9%								0%	14%	2%	67%		6%	0%		100%	2%	39%	0%
		%>Lopt, <Mega		31%	0%	19%	23%	2%								4%	20%	0%	0%		0%	17%		0%	0%	0%	22%
		% Mega		32%	0%	76%	14%	1%								93%	44%	1%	0%		0%	9%		0%	0%	0%	0%
	L4	<Lmat		13%	100%	3%	58%	94%								0%	25%	92%	39%		100%	65%			99%	99%	53%
		>Lmat		87%	0%	97%	42%	6%								100%	75%	8%	61%		0%	35%			1%	1%	47%
		%>Lmat, <Lopt		11%	0%	0%	32%	4%								1%	24%	6%	61%		0%	0%			1%	1%	6%
		%>Lopt, <Mega		34%	0%	21%	5%	1%								1%	22%	0%	0%		0%	27%			0%	0%	0%
		% Mega		43%	0%	77%	5%	0%								98%	29%	2%	0%		0%	9%			0%	0%	40%
Semi-pelagic longline	Ls1	<Lmat	0%	0%	100%				3%	23%		48%									67%		95%				
		>Lmat	100%	100%	0%				97%	77%		52%									33%		5%				
		%>Lmat, <Lopt	0%	0%	0%				23%	11%		27%									33%		5%				
		%>Lopt, <Mega	6%	0%	0%				14%	12%		18%									0%		0%				
		% Mega	94%	100%	0%				60%	54%		8%									0%		0%				
	Ls2	<Lmat	0%		100%				12%	24%		46%									41%		96%				0%
		>Lmat	100%		0%				88%	76%		54%									59%		4%				100%
		%>Lmat, <Lopt	0%		0%				17%	14%		31%									59%		4%				0%
		%>Lopt, <Mega	0%		0%				28%	13%		15%									0%		0%				0%
		% Mega	100%		0%				43%	49%		8%									0%		0%				100%
	Ls3	<Lmat	0%		100%				19%	28%		44%									45%		76%				
		>Lmat	100%		0%				81%	72%		56%									55%		24%				
		%>Lmat, <Lopt	0%		0%				25%	16%		28%									50%		24%				
		%>Lopt, <Mega	9%		0%				11%	15%		18%									5%		0%				
		% Mega	91%		0%				44%	41%		10%									0%		0%				
	Ls4	<Lmat	0%		84%				14%	18%		48%									64%		76%				
		>Lmat	100%		16%				86%	82%		52%									36%		24%				
		%>Lmat, <Lopt	0%		16%				20%	14%		25%									29%		24%				
		%>Lopt, <Mega	5%		0%				22%	17%		19%									7%		0%				
		% Mega	95%		0%				44%	51%		8%									0%		0%				

Table 3.5 Indicators (length at maturity, optimum length and megaspawners) of the most important species in number for each gear size of trammel net, crustacean trawl and fish trawl.

			species																								
Gear	Gear size	Indicator	*Benthodesmus elongatus*	*Boops boops*	*Conger conger*	*Diplodus bellottii*	*Diplodus sargus*	*Diplodus vulgaris*	*Etmopterus pusillus*	*Galeus melastomus*	*Macroramphosus spp.*	*Merluccius merluccius*	*Microchirus azevia*	*Micromesistius poutassou*	*Mullus surmuletus*	*Pagellus acarne*	*Pagellus erythrinus*	*Pagrus pagrus*	*Phycis phycis*	*Sardina pilchardus*	*Scomber japonicus*	*Scorpaena notata*	*Scyliorhinus canicula*	*Solea senegalensis*	*Spondyliosoma cantharus*	*Trachinus draco*	*Trachurus trachurus*
Trammel net	Tr1	<Lmat		16%	100%	8%		54%				97%	23%	100%	0%	5%	16%	75%	74%	0%	55%	35%	65%	26%	79%	82%	100%
		>Lmat		84%	0%	92%		46%				3%	77%	0%	100%	95%	84%	25%	26%	100%	45%	65%	35%	74%	21%	18%	0%
		%>Lmat, <Lopt		30%	0%	0%		31%				0%	24%	0%	0%	17%	0%	14%	19%	0%	44%	0%	35%	58%	21%	16%	0%
		%>Lopt, <Mega		29%	0%	61%		14%				0%	19%	0%	0%	45%	9%	0%	4%	0%	1%	35%	0%	14%	0%	2%	0%
		% Mega		24%	0%	31%		0%				3%	33%	0%	100%	33%	75%	11%	2%	100%	0%	30%	0%	2%	0%	0%	0%
	Tr2	<Lmat		11%	100%	0%	40%	60%				88%	17%	100%	0%	12%	5%	57%	71%	0%	38%	44%	79%	45%	93%	80%	100%
		>Lmat		89%	0%	100%	60%	40%				12%	83%	0%	100%	88%	95%	43%	29%	100%	62%	56%	21%	55%	7%	20%	0%
		%>Lmat, <Lopt		11%	0%	0%	0%	33%				4%	27%	0%	0%	19%	8%	43%	12%	0%	58%	0%	21%	40%	7%	18%	0%
		%>Lopt, <Mega		36%	0%	0%	60%	7%				6%	23%	0%	14%	22%	8%	0%	7%	0%	4%	34%	0%	9%	0%	2%	0%
		% Mega		41%	0%	100%	0%	0%				2%	32%	0%	86%	47%	79%	0%	10%	100%	0%	22%	0%	6%	0%	0%	0%
	Tr3	<Lmat		2%	67%	39%		24%				87%	20%		0%	2%	28%	4%	81%	0%	44%	30%	43%	9%	90%	74%	100%
		>Lmat		98%	33%	61%		76%				13%	80%		100%	98%	72%	96%	19%	100%	56%	70%	57%	91%	10%	26%	0%
		%>Lmat, <Lopt		6%	33%	0%		44%				3%	32%		0%	7%	3%	28%	9%	0%	51%	0%	37%	42%	10%	24%	0%
		%>Lopt, <Mega		26%	0%	27%		19%				2%	21%		0%	20%	9%	19%	1%	2%	4%	24%	0%	35%	0%	1%	0%
		% Mega		66%	0%	33%		12%				9%	27%		100%	71%	60%	49%	9%	98%	0%	46%	19%	14%	0%	0%	0%
	Tr4	<Lmat		0%	100%	26%	26%	55%				89%	20%		0%	1%	27%	0%	70%	0%	53%	35%	63%	5%	87%	77%	100%
		>Lmat		100%	0%	74%	74%	45%				11%	80%		100%	99%	73%	100%	30%	100%	47%	65%	37%	95%	13%	23%	0%
		%>Lmat, <Lopt		0%	0%	0%	74%	24%				3%	31%		0%	3%	9%	12%	11%	0%	46%	0%	37%	43%	13%	18%	0%
		%>Lopt, <Mega		39%	0%	16%	0%	21%				6%	23%		0%	9%	7%	54%	4%	0%	0%	26%	0%	35%	0%	3%	0%
		% Mega		61%	0%	58%	0%	0%				2%	26%		100%	86%	57%	35%	15%	100%	0%	38%	0%	16%	0%	1%	0%
	Tr5	<Lmat		3%	67%	0%	0%	100%				92%	22%	100%	0%	0%	13%	18%	62%	0%	57%	9%	81%	2%	93%	73%	100%
		>Lmat		97%	33%	100%	100%	0%				8%	78%	0%	100%	100%	87%	82%	38%	100%	43%	91%	19%	98%	7%	27%	0%
		%>Lmat, <Lopt		5%	33%	0%	21%	0%				2%	27%	0%	0%	0%	35%	0%	22%	0%	42%	0%	19%	11%	7%	19%	0%
		%>Lopt, <Mega		32%	0%	0%	0%	0%				4%	20%	0%	0%	5%	4%	0%	4%	0%	1%	11%	0%	38%	0%	8%	0%
		% Mega		60%	0%	100%	79%	0%				2%	31%	0%	100%	95%	47%	82%	12%	100%	0%	80%	0%	50%	0%	0%	0%
	Tr6	<Lmat		0%	100%	0%	100%	100%				89%	12%		0%	0%	29%	51%	66%	0%	50%	19%	62%	6%	96%	73%	100%
		>Lmat		100%	0%	100%	0%	0%				11%	88%		100%	100%	71%	49%	34%	100%	50%	81%	38%	94%	4%	27%	0%
		%>Lmat, <Lopt		0%	0%	0%	0%	0%				6%	27%		0%	0%	18%	0%	19%	0%	48%	0%	38%	15%	0%	20%	0%
		%>Lopt, <Mega		19%	0%	100%	0%	0%				5%	27%		0%	2%	7%	9%	7%	0%	2%	36%	0%	33%	4%	7%	0%
		% Mega		81%	0%	0%	0%	0%				0%	34%		100%	98%	45%	41%	8%	100%	0%	45%	0%	46%	0%	0%	0%
Crustacean trawl	Tw1	% <Lmat	4%	23%	100%	0%		91%	64%	92%	28%	99%	100%	65%	0%	50%	100%		73%	0%	73%	84%	96%		100%	100%	90%
		% >Lmat	96%	77%	0%	100%		9%	36%	8%	72%	1%	0%	35%	100%	50%	0%		27%	100%	27%	16%	4%		0%	0%	10%
		%>Lmat, <Lopt	12%	10%	0%	0%		6%	21%	4%	29%	1%	0%	6%	14%	4%	0%		9%	0%	22%	0%	4%		0%	0%	8%
		%>Lopt, <Mega	17%	38%	0%	0%		3%	10%	1%	29%	1%	0%	9%	0%	4%	0%		9%	0%	3%	9%	0%		0%	0%	2%
		% Mega	68%	29%	0%	100%		0%	6%	3%	14%	0%	0%	20%	86%	42%	0%		9%	100%	2%	7%	0%		0%	0%	0%
Fish trawl	Tw2	% <Lmat	10%	14%	100%	0%		97%	68%	89%	25%	98%	100%	62%	1%	1%	85%		64%	0%	50%	81%	99%		99%	100%	99%
		% >Lmat	90%	86%	0%	100%		3%	32%	11%	75%	2%	0%	38%	99%	99%	15%		36%	100%	50%	19%	1%		1%	0%	1%
		%>Lmat, <Lopt	0%	17%	0%	0%		3%	9%	2%	27%	2%	0%	9%	1%	0%	9%		2%	0%	13%	0%	1%		0%	0%	1%
		%>Lopt, <Mega	30%	38%	0%	9%		0%	5%	2%	28%	0%	0%	12%	0%	1%	4%		0%	0%	5%	13%	0%		0%	0%	0%
		% Mega	60%	31%	0%	91%		0%	18%	6%	20%	0%	0%	17%	98%	97%	1%		33%	100%	32%	6%	0%		1%	0%	0%

4. Discussion

Species relative composition of catches

The artisanal fishery of the Algarve has a great complexity due both to the multispecific character of the catches and to the variety of gears involved. This fishery is sustained by a few species or groups of species: Sparidae, *Merluccius merluccius*, *Sepia officinalis* or *Scomber japonicus* that have large variations in relative abundances between the different gears, which is partly explained by the fishing strategy decided by the fishers (e.g. depth, fishing grounds) (PELLETIER and FERRARIS, 2000) and the gear selectivity (STERGIOU *et al.*, 2006).

Some species were caught almost exclusively by gill nets (e.g. the main target species *Mullus surmuletus*) and others by bottom longline (e.g. the target species *Diplodus sargus*), yet many species were common to both gears (e.g. *Diplodus bellotti*, *D. vulgaris, Pagellus* sp., *Scorpaena notata*). Trammel nets mainly target flatfish and cephalopods, but species such as *S. japonicus*, although caught in low percentages, are common, while this species is one of the most important in gill net catches. The semi-pelagic longlining successfully targeted hake (*M. merluccius*). In contrast with the artisanal fleet, the target and most important species of the crustacean trawlers are crustaceans (*Nephrops norvegicus*, *Parapenaeus longirostris* and *Aristeus antenatus*) while for fish trawlers the hake (*M. merluccius*) and the blue whiting (*Micromesistius poutassou*) dominate the catches.

The resemblance of the species that contribute to the catches of gill nets, trammel nets and bottom longline is most probably due to the fishing grounds where these gears are deployed which are the same, with the exception that for trammel nets the areas were greater and reached deeper waters than gill nets and small hook bottom longlines, while trawls were always deployed close to or on the continental slope.

Diversity and species richness indicators

Preservation of naturally occurring biodiversity is an objective to avoid impoverishment and extinctions (i.e. habitat simplification) as species rich communities appear to be more resistant and buffer natural fluctuations. The loss of biodiversity will diminish the capacity of the ecosystem to provide stable and sustainable supply of essential goods (TILMAN, 2000).

Fishing affects species diversity by killing target and non-target species of fish and invertebrates and by changing habitat structure and, in this way, trawls and trammel nets are the gears that most stress the community. Trammel nets and trawls affect a very wide number of benthic species that are non commercial and that are discarded (see ERZINI *et al.*, 2002) and the disturbance bottom trawls have on habitats is likely to be more significant compared with set nets and longlines (CHUENPAGDEE *et al*., 2003).

More diverse catches can result from the exploitation of heterogeneous environments, as was the case with trammel nets and trawls where the depth ranges were wider. In the case of the semi-pelagic longline, the low number of species in the catches can be explained by the high selectivity of this gear (ERZINI *et al.*, 2001a) or the homogeneous environment where it operates (FRÉDOU *et al*., 2006). Semi-pelagic longlining took place at much deeper fishing grounds than the other static gears and where only longlining is allowed (ERZINI *et al*., 2001a). The low number of species affected by gill nets and bottom longline can be a reflection of a more homogeneous environment or the heavy fishing pressure in those fishing grounds.

The Shannon-Wiener index suffers from combining two distinct facets of diversity-species richness and the way individuals are distributed among species (evenness). These may work in opposite directions and their effects are confounding, so major changes in a community may result in similar diversity indices (HURLBERT, 1971). Heavy exploitation can often lead to an increase in diversity, e.g. by an influx of new species or by an increase in abundance of formerly rare species (BIANCHI *et al*., 2000).

Mean length indicator

Mean length in the catch is a meaningful indicator in a gear management context, as it allows for discrimination between impacts of different fishing gears (NICHOLSON and JENNINGS, 2004; BLANCHARD *et al*., 2005). The mean fish size of a species is sensitive to gear selectivity (ERZINI *et al.*, 1999; 2001a; 2006) and spatial distribution of individuals (HUSE *et al*., 2000; SHIN *et al*., 2005). However, it is not specific to fishing impacts as a reduced mean size of a species can be explained by a low abundance of the large targeted fish and (or) strong recruitment. In contrast, a low mean size of fish in catches can only reflect a low abundance of large fish (ROCHET and TRENKEL, 2003; SHIN *et al.*, 2005; TRAVERS *et al*., 2006). It can be less robust because it is more sensitive to a few outlying observations and to a lack of precision in size estimation (AMAND *et al*., 2004). When weighted by abundance of the catch, the variation of the mean size is mostly due to the relative abundances of species rather than the mean size of species (TRAVERS *et al*., 2006).

Gill nets and trammel nets were, generally, more size selective than trawls or longlines, since the catches are composed of a relatively narrow length range. Fish caught by gillnet are mainly gilled by the meshes and this gear, therefore, catches fish within a narrow range of sizes (HUSE *et al*., 2000). The size selectivity of each mesh will not show directly what fraction of the available fish population it will catch, but rather the proportion of fish it will capture relative to other mesh sizes (SANTOS *et al*., 1998).

Trawls were less size selective than others, as they catch fish that are present in their path and due to the use of very small mesh sizes in cod ends, retain almost all animals encountered by the gear (STERGIOU *et al*., 1997; HUSE *et al*., 2000). Trawl catches comprised a wide range of sizes, in particular those of fish trawl, with smaller individuals when compared with those of the same species caught by the other gears. When the majority of the fish retained is smaller than the minimum legal size, they are discarded or marketed illegally (STERGIOU *et* *al*., 1997). Longline fisheries exploit the feeding behaviour of the fish and will exclude small fish from the catches only when larger specimens are present (HUSE *et al*., 2000). Larger fish or large species can become rare in the catches because they are rare in the exploited fish community, their catchability is low for the gears used or, for most the cases, they are overfished.

ROCHET and TRENKEL (2003) state that the reference point for mean length in catch should be higher than the median length at maturity, to ensure that at least 50% of all the individuals in the cohort spawn at least once. Thus, the median length of the catch is also an important index to calculate.

Mature, optimum sized and megaspawner indicators

To avoid recruitment overfishing (i.e. reduction of the ability of fish to reproduce), the catch of immature individuals must be minimal. Fish should be permitted to spawn at least once before they become vulnerable to commercial gear, so that stocks will not collapse if fishing mortality targets are breached. To avoid growth overfishing (i.e. catching fish before they can fully realize their growth potential), fish should be caught with optimum size. The older members (megaspawners) of the fish population must not be captured (FROESE, 2004) to avoid loss of genetic variability that potentially leads to reductions in adaptability, population production and persistence (BIRKELAND and DAYTON, 2005),

Juveniles in shallower waters are susceptible to increased fishing pressure by gill nets, bottom longlines and trammel nets while mature individuals are more protected in deeper waters, which contributes to the persistence of stocks of the species that seek refuge in greater depths (e.g. *M. merluccius* and *S. japonicus*) (e.g. ERZINI *et al*., 2001a). The smallest mesh size of gill net is less suitable for the conservation of species like *S. notata*, *D. bellottii* and *P. erythrinus* because it affects largely the juvenile fraction of these populations. The high abundance of immature fish in the catch of the larger mesh of gill nets can be explained by the high contribution of immature *S. japonicus*, which was approximately twice the contribution for the other mesh sizes. Thus, the larger mesh allows the escapement of mature individuals of smaller species that still are a target for this fishery. Therefore, an appropriate mesh size for this fishery should be intermediate. The bottom longline was a more appropriate gear to target *P. erythrinus* as more mature individuals were captured, though not appropriate for *D. vulgaris* or *S. cantharus*, as the majority of the catches were immature. The larger hook size of the bottom longline caught fewer juveniles of the main target species (*D. sargus*), which is important in view of sustainability of this species. The larger mesh size combination of trammel nets should be considered for the flatfish, as it captured fewer juveniles and more optimum sized fish, while for *S. japonicus* there is no distinction between mesh size combinations concerning the sustainability of this species. Trawls affect the sustainability of many target species of the static gears (*M. merluccius*, *S. japonicus*) as they catch many juveniles of these species due to the poor selectivity of the gear (e.g. GARCÍA-RODRIGUEZ *et al*., 2006).

Semi-pelagic longline affects the sustainability of *M. merluccius* as half the catch is immature. The elasmobranch *S. canicula* is fished unsustainably by this gear as more than 75% are juveniles. This species is very susceptible to fishing impact because of its low fecundity and high length and age at maturity (MYERS and MERTZ, 1998; STEVENS *et al*., 2000; SADOVY, 2001). Species such as *B. elongatus, E. pusillus, G. melastomus* seem to be fished sustainably as few juveniles were affected by this gear, nevertheless very high percentages of megaspawners were caught. The removals of megaspawners contribute to the difficulty that some populations experience in recovering from overexploitation, as larger individuals in a population are much more fecund (the number of eggs increases exponentially with length in most species and their eggs also tend to be larger, thus giving a greater chance of survival to larvae) and can enhance the survival and reproductive success of the next generation

(SADOVY, 2001; LONGHURST, 2002; FROESE, 2004; BIRKELAND and DAYTON, 2005; SHIN *et al*., 2005). Megaspawners of *M. poutassou* in the crustacean trawl and the fish trawl catches; *D. bellottii* and *P. acarne* in the gill net, bottom longline and trammel net catches; *M. surmuletus* in the gill net catches, were also highly affected.

Size at maturity and the other size-based indicators used in this study, require relatively few data and perform consistently regardless of the level of exploitation intensity and the structure of the underlying ecosystem (ROCHET and TRENKEL, 2003).

Trophic level indicator

Managing for sustainability and trophic level maintenance can be improved by determining the trophic levels being captured by the various gears, which associated with stable total catches suggest sustainability (PAULY *et al*., 2001). The typical pattern in developing fisheries is first to exploit large fish that generally feed at higher trophic levels, reducing the mean trophic level of the fish remaining in the system and then as the catch rates and yields drop, to exploit species at lower trophic levels. Thus, the fishery moves down the food web and eventually leads to declining trends of mean trophic level in the catches and the trophic structure of the ecosystem is simplified (PAULY *et al*., 2002; BUNDY *et al*., 2005; CURY *et al*., 2005b; GRAHAM *et al*., 2005).

The extent of disturbances in trophic structure can be minimized by focusing exploitation on the lowest and most productive trophic levels or on all trophic levels at some reasonable and equal proportion of production, but this may be economically unviable (BUNDY *et al*., 2005). Trawls affect many trophic levels (e.g. SANTOS and BORGES, 2001), which can be a reflection of a poor selectivity for species and size. Crustacean trawls caught a wider range of fish with higher trophic levels and thus, can strongly affect the mean trophic level of the fish species in the ecosystem. Semi-pelagic longlines catch a narrow range of piscivorous species, probably due to the exclusive fishing grounds and the gear selectivity. Bottom longline, trammel net and especially gill net catches had a lower but wider mean trophic level (mainly benthic invertebrate feeders), which can indicate heavy fishing in these fishing grounds. Thus, static nets and bottom longline contribute more to the maintenance of the trophic structure.

Fishing alters the species composition within spatial assemblages and thereby alters species interactions and this is an indirect impact of exploitation. When piscivores, e.g. elasmobranchs, in the community are strongly affected, species interactions can be modified through alterations in species compositions as predatory interactions strongly influence fish population dynamics (BAX, 1998; STEVENS *et al*., 2000; LINK and GARRISON, 2002; BUNDY *et al*., 2005). Releasing predation pressure on small fish can enhance their survival, which may lessen juvenile survival of large predatory species, thus inhibiting the rebuilding of depleted predator stocks (SHIN *et al*., 2005). But removing predators does not necessarily lead to more of their prey becoming available for humans; instead it can lead to large increases of previously suppressed species, often invertebrates (PAULY *et al*., 2002). Diversified food webs allow predators to switch between preys as their abundance fluctuates and hence to compensate for prey fluctuations induced by environmental fluctuations (LINK and GARRISON, 2002; PAULY *et al*., 2002) and exploitation.

Without historical data on the trophic level changes with gears at each fishing ground, it is difficult to distinguish the gear most responsible for the current mean trophic level. It could be that gears other than the mentioned in this study are responsible for the current trophic status and would be premature to place restrictions on gears without additional evidence for sustainable use (e.g. MCCLANAHAN and MANGI, 2004). A better understanding of the trophic structure depends on the knowledge of species feeding behaviour and diet composition (SANTOS and BORGES, 2001; CURY *et al*., 2005b; HEATH, 2005) through life (PAULY *et al*., 2001) in for particular sensitive species (STEVENS *et al*., 2000).

Management measures based on ecological indicators

The reduction of effort is the most effective step to reduce the effects of fishing on the ecosystem (FRID *et al*., 2005). Gear substitutions have a clear role to play in protecting habitat features and reducing bycatch (BREWER *et al*, 1996; FRID *et al*., 2005) and using gears that have low overlap in gear selectivity is necessary to achieve sustainable fisheries. Management measures must include shifting to gears that cause less ecological damage and the elimination of several gears in order to reduce the catch of small fish and overlap in the selectivity has been suggested by MCCLANAHAN and MANGI (2004) using body length, trophic level and diversity among gears as indicators to evaluate a complex multispecies and multigear fishery.

The studied gears affected the fish community in different ways (i.e. different species and sizes). There was an exploitation of different life stages of several species by different gears and, consequently, gear competition for the same resources (e.g. FRÉDOU *et al*., 2006). The crustacean trawling and the fish trawling, which present typical features of industrial fishing, have been shown to potentially affect ecosystems and to interfere indirectly with the artisanal activity for the fish catch. High abundances of immature hake, with sizes below the minimum legal size were captured with trawling, which inevitably produces a conflict between the two kinds of fishery. Sustainability is more likely to be achieved by reducing the use of trawls or the mesh sizes of the nets and management procedures must be implemented or strengthened in order to reduce the catches of recruits by trawlers (e.g. GARCÍA-RODRIGUEZ *et al*., 2006). Adjusting the mix of gears can help to maintain a constant mean trophic level of the catch (MCCLANAHAN and MANGI, 2004) and optimise the yields according to the abundance of potential target species in order to sustain the artisanal fishery by a few species of high commercial value (GARCÍA-RODRIGUEZ *et al*., 2006).

Because of the multispecies nature of the fisheries, any increase in minimum mesh size would not be suitable during all fishing seasons and for all fishing practices, as it would greatly impact on the retention of other important species. More selective and appropriately configured nets would minimize the catch of non-target species or undersized individuals, but would eventually be more expensive (GRAY *et al*., 2005). Higher selectivity is possible on industrial fishing boats when using standard electronic equipment combined with modern gear technology and relevant information (MISUND, 1997).

The semi-pelagic longline appears to be a more sustainable gear because, in general, it is more species and size selective than the other gears in this study. Though no differences in size selectivity with hook size for hake were detected by ERZINI *et al.* (2001a) an increase in hook size should be considered to avoid catching immature hake and promoting the sustainability of this commercially important species. The spawn at least once policy or the reduction of the selection of younger fish are measures that will help the sustainability of several other species and setting the minimum landing size beyond size at first maturity is an important regulation to implement in that direction. Only in the cases of *P. acarne*, *D. bellotti* and *M. surmuletus* was the minimum legal size established very close to the length at maturity. For the other species the minimum legal size is much lower than this important biological reference point, which explains the length based discarding of most species, including high value species, as generally only larger individuals are retained (GRAY and KENNELLY, 2003).

Given that active gears are capable of causing severe damage to deeper habitats, which are potentially important in the life history of commercial fish species, it is prudent to adopt a precautionary approach for the management of deeper fisheries and to protect some of the areas (TURNER *et al*., 1999). A common harvesting strategy may not be applicable for the entire fishing area and alternative management policies applied to smaller segments of the fishing area can provide a buffer against risks of overexploitation (FRÉDOU *et al*., 2006; CLAUDET *et al*., 2006). Marine protected areas can refuge the larger and older individuals of long-lived species (BIRKELAND and DAYTON, 2005; MYERS and WORM, 2005); reduce fishing on spawning stocks and juveniles; increase fish abundance within the protected area and promote spillover of the increased fish abundance into adjacent areas where it may lead to improved catches. By reducing fishing effort, protected areas can contribute to ecosystem conservation and may enhance or preserve local biodiversity (PAULY *et al*., 2002; DEGNBOL *et al*., 2006). Still little is done to protect migratory species (CLAUDET *et al*., 2006; DEGNBOL *et al*., 2006) and effort displacement to regions beyond those protected may enhance stock depletion there (BRANCH *et al*., 2005; MYERS and WORM, 2005).

Management measures can be improved when ecological indicators consider seasonal effects (PELLETIER and FERRARIS, 2000), spatial structure of the exploited stocks, habitat use, migrations and biological parameters along with gear performance (FREIRE and GARCÍA-ALLUT, 2000). The impact of natural disturbances on ecosystem dynamics is consistent with the effects of fishing and will need to be considered, especially with the increasing climate variability linked to global warming (FRID *et al*., 2005; HEATH, 2005). ERZINI (2005) in his study showed that local environmental conditions could have a significant influence on fluctuations in landings of short-lived species (e.g. sardine, shrimps, cuttlefish) in the Algarve, while species considered long lived (e.g. hake) are more susceptible to fishing mortality.

To interpret ecological indicators is important to understand the dynamics of the fishery (CURY *et al*., 2005b; SHIN *et al*., 2005) and multiple indicators, each sensitive to a particular aspect of structural variation, are required to assess the status of fish communities and accumulate evidence (GREENSTREET *et al*., 1999; GARCIA and STAPLES, 2000; RICE, 2000; LINK *et al*., 2002). Ecological indicators representative of major processes and sensitive to fishing can be identified with high quality time-series (LINK *et al.*, 2002; NICHOLSON and JENNINGS, 2004; HEATH, 2005) and the identification of redundant indicators, that represent similar properties and processes, will help to reduce costs and more effectively assess and communicate ecosystem status (METHRATTA and LINK, 2006). The role of target and non-target species and size classes can be better understood when comparing indicators in the ecosystem and in the catches as these only concern recruited stages (TRAVERS *et al*., 2006).

The ecological indicators applied at the level of individual fish can enable fishers and consumers to participate more actively in fisheries management. One example is the ‘fish ruler’, with pictures and lengths at maturity, which can be distributed widely encouraging consumers to assess by themselves the fishes being sold to ensure they are not buying juveniles (FROESE, 2004) or threatened species. Ecolabelling provides the option to buy sustainable harvested products (e.g. avoiding products that involved certain bycatch) (PAULY *et al*., 2002; JACQUET and PAULY, 2007) and Ecocertification of sustainable fisheries and of harvesting practices puts a price on an ecosystem service (GRAFTON *et al*., 2006).

Fishery policies should encourage a shifting or modification of gears from the higher to lower ecological impact and incentives should be given to fishers who voluntarily shift gears (GRAFTON *et al*., 2006). Fishers knowledge and judgement can also be integrated to assess the relative severity of ecological impacts of the different fishing gears (CHUENPAGDEE *et al*., 2003). Fishers learn which gear to use and what time of the year to fish at a certain fishing location for high rates of target species (BRANCH *et al*., 2005) while industrialized fisheries present a strategy of intense and continuous exploitation of the same resources in similar habitats using one or a few gears (FREIRE and GARCÍA-ALLUT, 2000).

Management should be viewed as a process of constant learning about the resource and the fisheries, which enables management improvement. The suite of indicators must gradually adapt to management needs, data constraints and scientific evaluations of the usefulness of the selected indicators (RAAKJÆR *et al*., 2007) and consensus on objectives, reference points and decisions for fisheries management among numerous stakeholders will be required at the local scale (CURY *et al*., 2005a).

5. *Conclusions*

It is proposed that the use of mean body length, mature length, optimum length, megaspawner length, trophic level, diversity and resource use between different gears and gear sizes are a relatively simple way to evaluate a complex multispecies and multigear fishery and to develop simple gear-based management guidelines.

The interpretation of the indicators always requires looking in detail at species composition. Several gears appear to be competing for fisheries resources rather than exploiting a unique fish resource. Reducing effort, changing gear and regulations on the minimum legal size appear to be relatively easy way to increase fish stocks and their sustainable extraction. The conclusions are limited to the time and spatial extent of the samplings, though there are differences in resource capture in different areas of the coastline.

The mesh size and the hook size more suitable for the conservation of species is the one that will capture more mature, preferentially optimum sized fish and few megaspawners. Attention should be given to whole catch as many species are present in the catches and can be captured at different life stages, which can impact their sustainability, even if not targeted by that gear. This study suggests also the need for closed areas mainly for the protection of the very impacted older fish.

Consumers can effectively encourage gears, which are more easily managed. The public participation will be very important to implement unpopular measures as closed areas or exclusion of certain gears among many others measures. Education of fishers and the public about the importance of ecosystem impacts by the different fishing gears and the need for ecologically friendly practices are a step towards fisheries sustainability.

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