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## *Ecosystem-based assessment of the effects of increasing trawl selectivity in the Mediterranean*



Switching to square-meshed nets -  
A first step on the long journey towards sustainability

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## **1. Introduction and Objectives**

The Mediterranean Sea is a region of outstanding importance in terms of biodiversity (Bianchi and Morri 2000). Together with exploited species, Mediterranean ecosystems also harbor important populations of turtles and cetaceans, as well as unique critical habitats such as phanerogam beds. Concurrently, the Mediterranean region has been inhabited for millennia and human settlements have been spreading continuously along the region, now reaching approximately a total of 132 million people along the coast (<http://www.edc.uri.edu/lme>). Marine Mediterranean ecosystems have thus been altered in many ways due to the overexploitation of biological resources, direct habitat modification of the sea and coastal areas, introduction of exotic species, pollution and climate change (Bianchi and Morri 2000, Papaconstantinou and Farrugio 2000).

Fishing activity has been proposed as the first major human disturbance to coastal areas (Jackson et al. 2001), and evidence of fishing activity going back to ancient times can be found all around the Mediterranean Sea (Margalef 1985). This is emphasised by a much lower starting value of the mean trophic level of the catch in the past 50-year historical series for the Mediterranean Sea when compared to marine areas of the world (Pauly et al. 1998). Two important features of the fishing activity in the Mediterranean Sea are the multi-specificity of catches and the absence of large single stocks, especially in the demersal regime, compared to those which inhabit other seas (Farrugio et al. 1993). Moreover, although artisanal gears are still important within the Mediterranean basin, most fleets have developed towards a nearly industrial type of activity (or semi-industrial fleets) fully exploiting continental shelves and upper slopes of the basin, associated with the highest landings and mainly composed of bottom trawlers, purse seiners and longliners (Lleonart and Maynou 2003).

The development of fishing technologies and overcapitalization, with an increasing demand for marine products, is placing intensive pressure on marine resources in the Mediterranean basin. The general assessment highlights that most demersal commercial stocks are fully exploited or over-exploited, while some pelagic commercial stocks also show overexploitation trends in the northern areas (Farrugio et al. 1993, Aldebert and Recasens 1996, Sardà 1998, Papaconstantinou and Farrugio 2000, Lleonart and Maynou 2003, Bas et al. 2003, Palomera et al. 2007).

Bottom-trawling is the operating gear in the Mediterranean Sea that shows the least degree of selectivity, has the widest-ranging impact on different organisms of the ecosystem due to habitat destruction and modification (important in terms of demersal biodiversity, Demestre et al. 2000), and the largest impacts on some demersal target species and non-target groups (i.e. small organisms discarded and juveniles of vulnerable species such as rays and demersal sharks). In this regard, there is an increasing concern about growth overfishing affecting some demersal resources because for many species the sizes at first

catch are very similar to those at which the fish recruit (Lloret and Lleonart 2002, Sardà et al. 2004 and 2005) and are under the size at first maturity.

Another important issue of bottom-trawling activities is the high proportion of catch that is thrown back to the sea due to its non-commercial value or due to the sizes of the organisms being under the minimum legal landing size (Arcos 2001, Carbonell et al. 1998 and 2003, Sardà et al. 2004, Sánchez et al. 2004, Tudela 2004). This is one of the main impacts of this fishing fleet on marine Mediterranean communities. With the current 40 mm diamond-mesh codend used by bottom-trawling, for example, the 50% selection length (L50) of European hake (*Merluccius merluccius*) is approximately 10 cm. This is about half of the official minimum landing size (20 cm) and about one-third of the size at first maturity for this species (Recassens et al. 1998, Bahamon et al. 2006).

A general assessment of the Mediterranean basin evaluated that the average discard by all fishing activities is about 5% (Kelleher 2005). However, much higher estimates are assessed when analysing local case studies in detail. In the Catalan Sea, the discarded biomass averages one third of the total captured biomass of a vessel and is mainly composed of non-commercial species, where aprox. 100 species are landed and 300 species are discarded (Sánchez et al. 2004). In the Adriatic Sea, important amounts of discards are also produced by bottom-trawling (Wieczorek et al. 1999, Pranovi et al. 2000 and 2001).

A new EC Regulation on the Management of Mediterranean Fishery Resources (CE 1967/2006) was approved in December 2006 concerning the management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea. In this text, it was highlighted that - “it is necessary to adapt new technical measures for fishing ... laying down certain technical measures for the conservation of fishery resources in the Mediterranean to take account of new scientific advice” - and - “ in order to avoid further increases in mortality rates for juveniles and to substantially reduce the amount of discards of dead marine organisms by fishing vessels, it is appropriate to provide for increases in mesh sizes and hook sizes for trawl nets, bottom-set nets and long lines, used for fishing for certain species of marine organisms and for the mandatory use of square-meshed netting”-. The new regulation enforces a universal adoption of the 40 mm square-mesh codend by July 2008 replacing the current 40 mm diamond-mesh codend (that has been derogated to 2010).

In this line of research, experimental case studies have been developed in different regions of the Mediterranean basin to assess the impact of increasing selectivity of bottom-trawling on demersal species by changing the current diamond-mesh codend to bigger mesh sizes, to square-mesh codends or by implementing sorting grids with different bar-spacing (see for example, Sardà et al. 1993, Petrakis and Stergiou 1997, Tokaç et al. 1998, Stewart 2001, Ragonese et al. 2002, D’Onghia et al. 2003, Sardà et al. 2004, 2005, 2006, Belcari and Viva 2005, Guijarro and Massutí 2006, Ordines et al. 2006, Zengin and Tosunoglu 2006, Bahamon et al. 2006, 2007a, 2007b, Baro and Muñoz de los Reyes 2007, GFCM 2007, Sala et al. in press).

Several of these experimental case studies explore the consequences of changing the current 40 mm diamond-mesh codend to 40 mm square-mesh codend. They have demonstrated that the square-mesh codend is more selective than the diamond mesh by increasing the L50 of most target species and by reducing discards (peer-reviewed publications are to date: Petrakis and Stergiou 1997, Tokaç et al. 1998, Bahamon et al. 2006, Baro and Muñoz de los Reyes 2007, Sala et al. in press). The first part of this report presents a summary of results from these studies performed in different areas of the Mediterranean.

However, higher rates of *predation mortality* and *post-escape mortality* are important issues to take into account when assessing the impact of selectivity on species and ecosystems and are not taken into account in single species studies mentioned above. Predation mortality, the mortality that is caused by predators of the ecosystem, is high in marine ecosystems, particularly in the case of small-sized species and juveniles. Post-escape mortality of organisms is the extra mortality associated with escapement from a gear. The organism that escapes from a selectivity device can be damaged and may thus die hours or days after escapement, or it may be more vulnerable to predation. If the survival of escapees is low (for example in the case of small pelagic fish), there may be no advantage to increasing the selectivity of trawl gear and derived management options could produce negative impacts due to the underestimation of the overall fishing mortality (Suuronen 2005). Escape mortality varies among species, fish size and environmental conditions, and can be immediate or delayed due to skin or internal organs damage, or to higher predation vulnerability (e.g. Suuronen et al. 1996a, 2005).

Therefore, the overall effect of improved selectivity on commercial species remains unclear unless the study is performed on an ecosystem context progressing towards an Ecosystem Approach to Fisheries (EAF). When setting the increasing trawl selectivity into an ecosystem context, the effect of this management measure can also be assessed for non-commercial species and for the ecosystem as a whole. These analyses have been developed in the Mediterranean by using the experimental data on trawl selectivity and developing temporal simulations using an ecological model that represents a typical ecosystem of the continental shelf and upper slope of the Mediterranean Sea: the Catalan Sea in the Western Mediterranean (Coll et al. 2008). The ecological model (Coll et al. 2006) considers the interactions between commercial and non-commercial species, represents all trophic levels of the ecosystem and takes into account fishing activities and the environment (Coll et al. 2005 and submitted). The second part of this report presents a summary of results from this study and includes the preliminary results of simulating ecosystem effects of improving selectivity of trawling in the Adriatic Sea as well. In this second case we used an available second model (Coll et al. 2007) that represents this area of the Central Mediterranean Sea and the experimental data of selectivity from the Catalan Sea (Bahamon et al. 2006, 2007a, 2007b). These results are therefore preliminary and should be taken into account

carefully. In addition, in this second part we include complementary simulations of fishing management using the southern Catalan Sea ecosystem model.

## **2. Methodology**

### **2.1. Impact of improved trawl selectivity on commercial species – a review**

Experimental case studies have been developed in different regions of the Mediterranean basin to assess the impact of increasing selectivity of bottom-trawling on demersal commercial species by changing the selectivity of the bottom-trawling using commercial fishing vessels or oceanographic vessels. Studies started during the mid 1990s and are currently still continuing in different Mediterranean regions such as the Spanish Mediterranean coast and Balearic Islands, Gulf of Lions and Tyrrhenian Sea, Adriatic Sea, Strait of Sicily, Ionian Sea, Tunisian waters and the Aegean Sea (Sardà et al. 1993, Petrakis and Stergiou 1997, Tokaç et al. 1998, Stewart 2001, Ragonese et al. 2002, D'Onghia et al. 2003, Sardà et al. 2004, 2005, 2006, Belcari and Viva 2005, Guijarro and Massutí 2006, Ordines et al. 2006, Zengin and Tosunoglu 2006, Bahamon et al. 2006, 2007a, 2007b, Baro and Muñoz de los Reyes 2007, GFCM 2007, Sala et al. in press).

A summary of different methodological tools can be found in Sala et al. in press. During these studies, the total lengths (TL) of fish were measured to the nearest cm in the codend and cover during fishing activities. With crustaceans the carapace length (CL) was measured to the closest mm. Afterwards, different approaches were applied to analyse the selectivity size and the 50% selection length (L50), calculate the fishing mortality, and simulate yield per recruitment (Y/R) and biomass/recruitment (B/R) after changing the selectivity of trawling. The general methodology followed for the Catalan case study is briefly explained below (from Bahamon et al. 2006, 2007a and 2007b). It has to be taken into account that these studies only focused on commercial species and did not take into account the direct and indirect impacts of fishing on the ecosystem and other species and trophic interactions, so variations on predation mortality and post-escape mortality were not included.

#### **a) Analysis of size selectivity**

In the Catalan Sea (Bahamon et al. 2006), logistic selection curves for individual hauls were fitted:

$$r_i(l) = \exp(a_i + b_i l) / [1 + \exp(a_i + b_i l)]$$

Eq.1

where  $r(l)$  is the probability of a fish with length  $l$  is retained by the net. The parameters  $a_i$  and  $b_i$  were estimated by maximising the log-likelihood function (Tokai 1997), assuming that the proportions observed are binomially distributed. Parameters  $a$  and  $b$  were used to calculate the mean selection length  $L50 = -a \times b^{-1}$ , and the selection range  $SR = L75 - L25 = 2 \times \ln(3) \times b^{-1}$ . Covariance



matrices provided the standard errors for individual  $a$  and  $b$  parameters. Over-dispersion of selectivity curves, when present, was corrected by multiplying the original standard errors by the square root of this estimate (Millar et al. 2004). Fixed and random mixed effects selectivity model was used for assessing between haul variability (Fryer, 1991). Details of the general methodology can be found in Wileman et al. (1996).

## b) Fishing mortality

In order to estimate the fishing mortalities by age, required to further perform the transition analysis, virtual population analysis (VPA) was conducted using the VIT program (Lleonart and Salat 1997). The program was created for the analysis of fisheries where information of the species is restricted to specific data in the absence of time series data. The program first calculates ages according to the von Bertalanffy equation:

$$l(t) = L_{\infty} (1 - e^{-K(t-t_0)})$$

Eq.2

where  $L_{\infty}$ ,  $k$  and  $t_0$  are constant. Then, the expected length frequencies are those estimated by lognormal method. Length frequencies are divided to each age interval proportionally.

To obtain the instantaneous fishing mortalities ( $F$ ) by age class, each population (age intervals) are reconstructed using the biological parameters for each species and the yearly estimates for catches in 2005, using the standard VPA. The VPA estimates the fishing mortality  $F$  by combining the catch equation:

$$C_i = F_i / Z_i N_{i+1} (e^{-Z_i \Delta t_i} - 1)$$

Eq.3

the  $N$  representing the survival equation for each class:

$$N_{i+1} = N_i e^{-Z_i \Delta t_i}$$

Eq.4

Given that  $Z_i = F_i + M$ , the  $F$  value is estimated by using an algorithm incorporating the method of the secant as described in Lleonart and Salat (1997).

## c) Transition analysis and simulations

Transition analyses were performed followed by the simulations of the long-term effects on yield per recruit (Y/R) and biomass per recruit (B/R) using the VIT software (Lleonart and Salat 1997). VIT program estimates the yield per recruit by dividing the total weight of the catch by the number of recruits calculated from the VPA, expressed as a function of the fishing effort factor  $\phi$ :

$$Y/R(\varphi) = 1 / N_i \sum_{i=1}^n \bar{N}_i \bar{w}_i F_i \varphi$$

Eq.5

In this analysis it is assumed a steady-state recruitment and constant fishing effort. Then simulations of Y/R and B/R are run by shifting current fishing mortalities with diamond-mesh codend to fishing mortalities produced by square mesh.

## **2.2. Ecosystem effect of improved trawl selectivity: analysis with ecological models**

After reviewing main experimental studies of the impact of increasing trawl selectivity in the Mediterranean Sea, we investigated whether an increase in trawl selectivity would have noticeable impacts on the ecosystem context using two case studies: the southern Catalan Sea and the northern and central Adriatic Sea. Using trophodynamic modelling we ran several simulations with selectivity data as fishing “experiments”. This work is partially published in Coll et al. 2008 and presented in Coll 2006. Results for the Adriatic Sea are preliminary.

### **a) Study areas**

The two study areas are located in the north-western and central Mediterranean Sea (Figure 1). The southern Catalan Sea area comprises the continental shelf and upper slope associated with the Ebro River Delta, and has a depth range between 50 m and 400 m. The southern Catalan Sea is predominately oligotrophic with some nutrient enrichment occurring due to regional environmental events related to wind conditions, a temporal thermocline, a shelf-slope current, and river discharge (Estrada 1996). The northern and central Adriatic Sea area constitutes the widest continental shelf in the Mediterranean Sea (Pinardi et al. 2006) and has a depth range between 10 m and 200 m. Owing to river runoff and oceanographic conditions, the region exhibits a decreasing trend of nutrient concentration and production from north to south and from west to east (Zavatarelli et al. 1998). Both areas are important for the reproduction of small pelagic fish (Agostini and Bakun 2002) and are also strategic areas for marine vertebrate conservation (Groombridge 1990, Zotier et al. 1998, Bearzi et al. 2004).

### **b) Selectivity experiments**

As explained in Coll et al. (2008), selectivity data were obtained from experiments conducted during the summer of 2005 on the commercial fishing grounds at depths between 100 m and 400 m in the southern Catalan Sea (Bahamon et al. 2006, 2007a, 2007b). Authors performed a total of 38 tows to assess the selectivity of the commercial 40 mm diamond-mesh codend (DM), and the experimental 40 mm square-mesh codend (SM) (Figure 2, examples of

square-mesh codend). A chartered commercial trawler and the standard covered codend method (Wileman et al. 1996) were used to assess selectivity. Selectivity analyses were performed on those species caught with sufficient frequency and in sufficient numbers, i.e. for hake, poor cod, blue whiting, greater forkbeard and Norway lobster (Bahamon et al. 2006, 2007a, 2007b). Other species recorded were considered as accompanying commercial species, i.e. marketable by-catch, and were measured in terms of total catch. Selectivity data expressed by length for DM and SM experiments were re-expressed in terms of total codend and total cover catches (kg) by tow for commercial species using available length-weight data (Table 1) (Bahamon et al. 2007a, 2007b). Data for the southern Catalan Sea was adapted for the northern and central Adriatic Sea.

### **c) Fishing and post-escape mortality estimates**

Using selectivity data, a VPA was performed to calculate mean fishing mortality rates of main target species (without considering post-escapement mortality) as explained in Coll et al. (2008). Steady state recruitment in the exploited fish stocks and a constant fishing effort were assumed. The analysis used the VIT software (Leonart and Salat 1997) and growth, length-weight and maturity parameters of each species shown in Table 1. Fishing mortality by species associated with DM and SM scenarios was then calculated for hake, poor cod, blue whiting, greater forkbeard and Norway lobster (Table 2). The percentage of catch reduction (kg) in the codend by experiment was also estimated (Table 2).

Data on the mortality of species caused by the escape from trawl gear (post-escape mortality) was extracted from the literature (Mediterranean and non-Mediterranean studies). This data shows some similarities between biological groups (crustaceans, demersal fishes, small-sized pelagic fishes) (see data in Appendix 1). General scenarios of post-escape mortalities by ecological groups were defined (Table 3) by considering the general quality (e.g. the number of replicates) of each study in the Appendix. The following general features were identified: (a) fishes show higher rates of post-escape mortality than crustaceans; (b) escape mortality decreases with increasing fish length; and (c) pelagic fish show higher escape mortalities than demersal species. This procedure is presented in Coll et al. (2008).

### **d) Trophodynamic modelling**

The ecological model from the southern Catalan Sea presented in Coll et al. (2006) and the model representing the northern and central Adriatic Sea summarized in Coll et al. (2007) were used to set the selectivity data presented above within the ecosystem context following the procedure presented in Coll et al. (2008).

The baseline model had been constructed using the Ecopath modelling approach (Christensen and Walters 2004a) that was used to ensure energy balance:

$$P_i = \sum_j B_j \cdot M_{2ij} + Y_i + E_i + BA_i + P_i \cdot (1 - EE_i)$$

Eq.6

where production (P) of each component or functional group (i) of the ecosystem equals predation mortality (M<sub>2ij</sub>) caused by the biomass (B<sub>j</sub>) of the other predators (j), exports from the system both in terms of fishing catch (Y<sub>i</sub>) and emigration (E<sub>i</sub>), biomass accumulation in the ecosystem (BA<sub>i</sub>) and baseline mortality or other mortality (1-EE<sub>i</sub>). EE is the ecotrophic efficiency of the group within the system, or the proportion of the production of (i) that is exported out of the ecosystem (i.e., by fishing activity) or consumed by predators within it. The energy balance within each group is ensured when consumption by group (i) equals production by (i), respiration by (i) and food that is unassimilated by (i).

The models represented an average annual situation of the ecosystem on the continental shelf and upper slope areas in the southern Catalan Sea and the northern and central Adriatic Sea during the 1990s (Coll et al. 2006 and 2007). They included 40 functional groups (Figure 3) spanning the main trophic components of the ecosystem from low to high trophic levels (TL), considering target and non-target vertebrate and invertebrate groups, detritus groups and main fishing fleets including bottom-trawling. In the case of the Catalan Sea model, poor cod, blue whiting and Norway lobster corresponded to single functional groups of the model, while greater forkbeard was included within “Demersal fish mixed-group (1)” (a mixed group of demersal fish species feeding on small demersal fish and crustaceans). Hake was divided into two functional groups, juvenile and adult hake, as data was available. In the case of the Adriatic Sea, Norway lobster corresponded to a single functional group, while hake was also divided into two functional groups (vulnerable to fishing and non-vulnerable to fishing) and poor cod, blue whiting and greater forkbeard were all included under the group called ‘other gadiformes’.

Time series from 1978-2003 and 1975-2000 of fishing effort by fleet, catches by species from governmental statistics, and biomasses of few commercial demersal and pelagic fishes and seabirds from oceanographic and fishing surveys, were used to calibrate the Catalan and Adriatic Sea models (Coll et al. 2005, submitted and unpublished data) applying the temporal dynamic module Ecosim (Christensen and Walters 2004a).

Ecosim describes a system of differential equations from the baseline mass-balance model (equation 1) where the growth rate during time of each functional group (i) in terms of its biomass ( $\delta B_i / \delta t$ ) is:

$$\frac{\delta B_i}{\delta t} = \left( \frac{P}{Q} \right)_i \cdot \sum Q_{ji} - \sum Q_{ij} + I_i - (M_i + F_i + e_i) \cdot B_i \quad \text{Eq.7}$$

where  $(P/Q)_i$  is the gross efficiency calculated from production (P) and consumption (Q) ratio;  $M_i$  is the non-predation natural mortality rate;  $F_i$  is the fishing mortality rate;  $e_i$  is the emigration rate;  $l_i$  is the immigration rate; and  $e_i \cdot B_i - l_i$  is the net migration rate. Calculations of Q by functional group are based upon the “foraging arena” theory where the biomass of (i) is divided between a vulnerable and non-vulnerable fraction and the transfer rate between the two fractions is what determines the flow control (bottom-up, top-down or mixed). Vulnerabilities by functional group, and an environmental anomaly function linked to phytoplankton production that takes into account environmental variability, were calculated as a result of the fitting process (Coll et al. submitted, and unpublished data). A critical review of Ecopath with Ecosim approach can be found in Christensen and Walters (2004a) and Fulton and Smith (2004).

### e) Selectivity simulations and analysis of results

Ecosim and the trophodynamic models representing the southern Catalan Sea and the northern and central Adriatic Sea provided with time series of biological data, vulnerability settings, environmental forcing functions and changes of fishing pressure from 1978 to 2003 and 1975 to 2000 (explained above) were used to derive two new models representing the ecosystem in 2003 and 2000 for the southern Catalan Sea and the northern and central Adriatic Sea, respectively. These new models were then used as the initial conditions for performing temporal simulations of expected scenarios after improving bottom-trawl selectivity, as explained in Coll et al. (2008).

The models were forced by changing fishing mortality ( $F_i$ ) in equation 7 and using a csv driver file (a comma-separated list or comma-separated variables file that stores tabular data). The new fishing mortality by functional group was calculated from the reduction of initial to final fishing mortality considering selectivity improvement and post-escape mortality (Table 2 and Table 3). Initially, simulations were run for 5 years without a change in fishing mortalities so that stability was reached prior to perturbation of the ecosystem, and then run for an additional 20 years (when the equilibrium was reached) considering the experimental selectivity data. Vulnerability settings from the calibrated model were included to perform dynamic simulations whereas the remaining ecological parameters and the environmental anomaly function was maintained by default from the initial model (Coll et al. 2005, submitted and unpublished).

The decrease in total fishing mortality ( $F_i$ ) by functional group ( $i$ ) with the square-mesh codend (SM) compared with that of diamond-mesh codend (DM, current situation) was a new input of the model and was calculated according to a decrease in fishing mortality (Table 2) based on equation 2 ( $F_i$ ) for the southern Catalan Sea:

$$F_{i,i} = F(pseine)_i + F(longline)_i + F(bait)_i + F(trawl)_{s,i}$$

Eq.8

where  $F(pseine)_i$  is the fishing mortality due to purse seining,  $F(long\ line)_i$  is due to long lining,  $F(bait)_i$  is due to bait trolling and  $F(trawl)_{s,i}$  is due to bottom-trawling after selectivity measures are applied. The potential increase of fishing-induced mortality due to escape (Table 3) was also taken into account as follows:

$$F_{i,i} = F(pseine)_i + F(longline)_i + F(bait)_i + (F(trawl)_{s,i} + F(trawl)_{e,i})$$

Eq.9

where  $F(trawl)_{e,i}$  is the increase of fishing mortality due to escape. For the northern and central Adriatic Sea case study this was performed similarly, taking into account purse seines, tuna fisheries, beam trawls, mid water trawls and bottom trawls and applying the selectivity data to the bottom-trawl fleet.

Three scenarios were simulated from 2003 and 2000 respectively, after the hypothetical introduction of the selectivity devices, considering selectivity data from:

Scenario 1: commercial species only using square mesh SM\_1;

Scenario 2: commercial species and a mean estimate for remaining accompanying species, marketable by-catch, and non-commercial species using square mesh, SM\_2;

Scenario 3: commercial, accompanying and non-commercial species, and post-escape mortality using square mesh, SM\_3.

Thus, scenario 3 was the most realistic scenario because it took into account mortality of fishing, decrease of mortality due to selectivity and post-escape mortality due to damage to organisms from selectivity devices.

The output of simulations was analysed following Coll et al. (2008) in terms of biomass ratios before ( $i$ ) and after ( $f$ ) selectivity ( $Bf/Bi$ ) by target and non-target demersal species or functional groups (2003-2030), total biomass ( $B$ ) and catch ( $C$ ) ratios ( $Bf/Bi$  and  $Cf/Ci$ ) and catch by fleet ( $t \cdot km^{-2}$ ). The overall ecosystem effects of selectivity measures were assessed by calculating: a) total ecosystem biomass ( $B_f/B_0$ ), b) total fishable biomass ( $Bf/Bf_0$ ), c) total top predator biomass ( $Bp_f/Bp_0$ ) (including adult hake, anglerfish, demersal sharks, Atlantic bonito, Atlantic bluefin tuna and swordfish), d) mean trophic level of the community (TLco), (e) mean trophic level of the catch (TLc), (f) total catches (Ct), and (g) a modified version of the Kemptons index of biodiversity (Pauly et al. 1998, Christensen and Walters 2004b). Both TLco and TLc indicators are expected to decrease when fishing impact increases because large predators are being reduced in ecosystems while lower TL organisms prevail (Pauly et al. 1998, Jennings et al. 2002). The modified version of the Kempton's index of biodiversity, or Biomass Diversity Index ( $Q'$ ), is a relative index of biomass diversity calculated from the Kempton's  $Q_{75}$  index developed for expressing species diversity (Kempton and Taylor 1976, Christensen and Walters 2004b).

This index includes those species or functional groups with a TL of three or higher, so an increase on this index implies the increase in biomass of various high TL organisms.

Because the data was not normally distributed and non-linear, the significance of Ecosim results in terms of biomass simulations was measured by applying the Spearman non-parametric correlation coefficient. Ecosim was used to test sensitivity of temporal simulation outputs to initial parameters of the baseline model by applying a Monte Carlo routine (Christensen and Walters 2004a, Christensen et al. 2005). To provide defaults for the Ecoranger routine of Ecopath, and thus allow explicit consideration of uncertainties in the inputs, model pedigree values (Coll et al. 2006) were used. Coefficients of variation (c.v.) set by default were: sampling based-high precision (c.v. = 10%), sampling based-low precision (c.v. = 30%); indirect method (c.v. = 50%) and other method (c.v. = 80%). Monte Carlo simulations were run with initial Ecopath estimates (B, P/B, Q/B and DC, equation 1) chosen from normal distributions centred on the initial inputs of the model. Each simulation begins by selecting random input combinations from the baseline model unless it is not balanced. The model results were used to develop dynamic simulations, and the mean and the standard deviation of 20 runs by simulation were calculated.

### **2.3. Complementary management options to recover Mediterranean ecosystems**

Following a similar methodology and using the ecological model representing the southern Catalan Sea that were presented in previous sections (section 2.2d and 2.2.e), we also developed simple complementary management scenarios to take a step forward and evaluate the ecosystem impact of more integral management based on Coll (2006).

To do so we used the southern Catalan Sea model representing the ecosystem in 2003 (Coll et al. 2005, submitted) and we performed alternative scenarios of fishing by changing the fishing effort and fishing mortality from 2003 to 2030. Vulnerability settings from the calibrated model mentioned before (1978-2003) were included to perform dynamic simulations whereas the remaining ecological parameters and the predicted environmental anomaly function were maintained by default from the initial model (Coll et al. 2005 and submitted).

The management scenarios analysed were the following:

- *Initial scenario*: Ecosystem state in 2003

The baseline scenario corresponded to the historical reconstruction of the ecosystem in 2003 as a result of the calibrating and fitting process from 1978-2003. Results of this scenario were used as a default to compare with scenarios 1-3.

- *Scenario 1*: Increase of trawl selectivity by implementing the square-mesh codend

Increase of trawl selectivity by implementing the square-mesh codend and taking into account the effect on commercial, non-commercial species and post-escape mortality (SM\_3 of previous section).

- *Scenario 2*: Increase of trawl selectivity and decrease of total fishing effort by 20%

Decrease of total fishing effort by 20% for all fleets to simulate the equivalent of a reduction in fishing effort by one day and increase of trawl selectivity (as in scenario 1).

- *Scenario 3*: Increase of trawl selectivity, decrease of total fishing effort by 20% and additional 20% reduction of fishing effort for the demersal fleets

Decrease of total fishing effort by 20% to simulate the equivalent of a reduction in fishing effort by one day for all the fleets, increase of trawl selectivity (as in scenario 1), and include an additional 20% reduction of fishing effort for the demersal fleets (trawling and demersal long lines, to simulate an extra reduction of fleet capacity for these fleets).

- *Scenario 4*: Maximum projection or ecosystem recovery

We added to the simulations a projection where all the fishing effort was eliminated from 2003 to 2030. Final results from this simulation are adopted as maximum projected values to compare with results from scenario 0-3.



### **3. Results and discussion**

#### **3.1. Impact of improved trawl selectivity on commercial species – a review**

In the Appendix 2 we present a summary of peer-reviewed, published trawl selectivity studies performed in five Mediterranean Sea regions (Catalan Sea, Balearic Islands, Alboran Sea, Adriatic Sea and Aegean Sea), applied to study the impact of improved trawl selectivity on commercial species by implementing the square mesh of 40 mm, or similar, on trawling devices.

In the Catalan Sea (North-western Mediterranean) (Bahamon et al. 2006, 2007a and 2007), experiments aiming at improving selectivity of bottom-trawling by shifting from the current 40 mm diamond-mesh codend to the 40 mm square-mesh codend have been conducted in the southern areas since the early 2000s. These studies focused on reducing the capture of immature individuals of target species. Single-stock assessment methods (Leonart and Salat 1997) were used to investigate the potential effects of improved trawl selectivity on the dynamics of commercial species. Selectivity experiments were mainly conducted on the commercial fishing grounds at depths between 100 m and 400 m in the southern Catalan Sea. A chartered commercial trawler and the standard covered codend method (Wileman et al. 1996) were used to assess the selectivity. Main target species were hake (*Merluccius merluccius*), blue whiting (*Micromesistius poutassou*), poor cod (*Trisopterus minutus*), greater forkbeard (*Phycis blennoides*) and Norway Lobster (*Nephrops norvegicus*) (Figure 4). On the continental shelf, hake, gurnard (*Chelidonichthys gurnardus*), spotted flounder (*Citharus linguatula*) and horned octopus (*Eledone cirrhosa*) were the most abundant species. Selectivity analyses were performed on those species caught with sufficient frequency and in sufficient numbers, i.e. hake, poor cod, blue whiting, greater forkbeard and Norway lobster. Other species recorded were considered as accompanying commercial species, i.e. marketable by-catch, and were measured in terms of total catch.

Bahamon et al. (2006) highlights that for European hake, Norway lobster, poor cod and greater forkbeard, the square mesh showed a significantly higher mean selection length ( $L_{50}$ ) than the diamond-mesh codend (which selects smaller organisms of the population due to smaller effective mesh size, and in some cases does not let any organism escape, such as in the case of the Norway lobster). This study thus suggests a substantial improvement in size-selectivity for these commercially important species, achieved by switching from 40 mm diamond-mesh codend to a 40-mm square-mesh codend (Figure 5). For Norway lobster, DM40 did not show any size-selectivity whereas SM40 produced a  $L_{50}$  of 22 mm, suggesting that it would improve selectivity. The short-term economic losses of commercial species from the square mesh, compared to the use of the 40 mm diamond-mesh codend, would be low in the slope fisheries (5%) and higher in the continental shelf (up to 30%).

Results presented by Bahamon et al. (2007a) for hake, Norway lobster, poor cod and greater forkbeard populations suggest that immediately after implementing the selectivity measures, the yield-per-recruit (Y/R) would be reduced by 20% for the three fish species, but that after 5 years the Y/R would increase by >50% if fishing effort were not changed (Figure 6). This study also highlights that overall marked long-term benefits could be obtained in the Catalan Sea by changing to 40 mm square-mesh codends.

In the case of the Balearic Islands (also in the North-western Mediterranean) (Guijarro and Massutí 2006, Ordines et al. 2006, Massutí et al. 2007), the experimental square-mesh codend has proven to be more selective than the 40 mm diamond mesh by increasing the  $L_{50}$  of target species, with the exception of the flatfish fourspotted megrim (*Lepidorhombus boscii*), and by reducing discards both in the shallow and deep waters. In the deep waters the authors showed that there are no differences in the species composition of catches and commercial yields of main species exploited with these two mesh types. In the shallow areas of the continental shelf, the introduction of the square mesh would not reduce the yields of main target species with the exception of picarell (*Spicara smaris*). In the short term, the escapement ratio and the economic loss with the diamond mesh were lower than with the square mesh (in the continental shelf mainly due to *S. smaris*), but economic efficiency was no different between them in the deep waters (Figure 7). In addition, the use of square mesh significantly reduced the discards of algae in the shallow waters and fish on the deep continental shelf (Figure 8). Therefore, the authors stated that within the precautionary management, introduction of the 40 mm square mesh in the codend could be an appropriate and plausible measure to improve the state of the resources exploited by the deepwater crustacean trawl fishery of the upper slope off the Balearic Islands.

In the north of the Alboran Sea (Baro and Muñoz de los Reyes 2007), three trawl surveys were also performed to determine differences between the 40 mm diamond and square-mesh codend. Main commercial species investigated were hake, blue whiting, red mullet (*Mullus barbatus*), the octopus *Octopus vulgaris* and the deepwater rose shrimp (*Parapenaeus longirostris*). Main findings demonstrated that there was no significant loss in fishing yields and that the length of first capture increased to similar or higher levels than the legally minimum length. The authors stated that the implementation of 40 mm square mesh in the codend could represent an appropriate management measure to improve the exploitation pattern of the trawl fleet in the Alboran Sea.

In the Adriatic Sea (Sala et al. in press), developed experiments on shallow waters of the central basin using 39 mm diamond mesh and square-mesh codends have shown an increase in selectivity using the square-mesh codend for various commercial species such as squid (*Illex coindetti*), hake, red mullet, Norway lobster, common pandora (*Pagellus erythrinus*), deepwater rose shrimp, horse mackerel (*Trachurus mediterraneus*) and poor cod. There was an exception for the flatfish *Arnoglossus laterna*, which was captured more with the square-mesh codend.

In the Aegean Sea, Petrakis and Stergiou (1997) performed experimental studies in the Trikeri Channel (western Aegean Sea) and in the northern Euboikos Gulf to assess the selectivity of diamond and square-mesh codends for four commercial species: hake, blue whiting, poor cod and the flatfish fourspotted megrim. This work showed that the diamond-mesh codend was harmful in terms of size of landed fish and the use of square mesh or higher diamond mesh size would facilitate the escapement of immature and under-sized individuals and would be accompanied by an increased yield per recruit. Another study in Turkish and international waters of the Aegean Sea (Tokaç et al. 1998) investigated the selectivity of 36, 40, 44 and 48 mm diamond and square-mesh codends. Results showed a significant increase in selectivity for red mullet, but results were not significant for annular sea bream (*Diplodus annularis*) and axillary sea bream (*Pagellus acarne*).

It has to be taken into account that these studies only focused on commercial species and did not take into account the direct and indirect impacts of fishing on the ecosystem and other species and trophic interactions, so variations on predation mortality and post-escape mortality were not included. Therefore, the increases in biomass and catch of commercial species were most likely overestimated.

### **3.2. Ecosystem effect of improved trawl selectivity: analysis with ecological models**

#### **a) Changes in biomass**

From an ecosystem perspective in the Catalan Sea, biomass ratios ( $B_f/B_i$ ) of commercial species (Figure 9a), when assuming that the whole trawler fleet is using a 40 mm square-mesh codend (SM), showed marked differences with respect to commercial species alone (scenario 1, SM\_1), commercial and accompanying species (scenario 2, SM\_2) and with post-escape mortality (scenario 3, SM\_3). In scenario 1 and 2, substantial variations in species biomass were observed, while in scenario 3 changes were more moderate. Scenario 3 showed that an increase in trawl selectivity would cause a significant decrease in the biomass of Norway lobster (8% from initial biomass), blue whiting (3%) and juvenile hake (11%), while there would be a significant increase for the demersal fish mixed-group (37%) and adult hake (6%). In the Adriatic Sea significant increasing changes on biomass were predicted by the model for the Norway lobster under all scenarios analysed (20 to 60%), and for hake during both SM\_1 and SM\_2 (54% and 43%) and the other gadoids under scenario SM\_1 (24%). A decrease on biomass was predicted for other gadoids under scenario SM\_3 (-10%) (Figure 9b).

Impacts on the biomass of other functional groups were also predicted. Top predators of the ecosystem apart from adult hake (with TL from 3 to 5) such as anglerfish, demersal sharks, Atlantic bonito and large pelagic fish (Figure 10a) showed greater changes in biomass when taking into account data from non-

commercial species and post-escape mortality in the Catalan Sea (i.e. under scenarios SM\_2 and SM\_3). This increase was significant for anglerfish under all scenarios. In the case study of the Adriatic Sea anglerfish also increased significantly under all tested scenarios, while demersal sharks and demersal skates also increased in biomass under SM\_2 and SM\_3. Small tuna showed high uncertainties (Figure 10b).

By main groups, total biomass of demersal invertebrates decreased in all scenarios (2-0.2% and 11-3%), while the biomass of demersal fish species increased (7-33% and 12-25%) in the Catalan Sea and Adriatic Sea (Figure 11). Total system biomass decreased in all scenarios in both study areas, but this decrease was not significant and in the case of the Adriatic Sea was predicted with high uncertainty. Fishable biomass also decreased non-significantly in both areas.

Therefore, various target and non-target demersal species would benefit from the implementation of improved trawl selectivity if we consider the results predicted from ecological models. This is due to a decrease in fishing-induced mortality and an increase in some of their preys. For example, anglerfish would mainly benefit from an increase in demersal fish and invertebrate components (Stergiou and Karpouzi 2002).

Predicted decreases in the biomass of low TL organisms can be explained by increasing predation; they are the main prey species of demersal fish which benefit from improved selectivity (Stergiou and Karpouzi 2002). Thus, although selectivity would favour them directly, this effect would be counteracted by the increase in predation mortality that would indirectly decrease their biomass, corresponding to trophic cascades occurring within the food web (Pace et al. 1999). This is the case of commercially important species such as Norway lobster, blue whiting and juvenile hake. Norway lobster is a secondary prey of anglerfish in the north-western Mediterranean (Ríos 2000). If anglerfish benefits from an increase in prey availability and a decrease in fishing-induced mortality, there would be a consequent increase in predatory mortality on its preys (e.g. Norway lobster). On the contrary, in the Adriatic Sea this species would benefit under all scenarios predicted. The potential decrease of juvenile hake biomass in the Catalan Sea is also due to an increase in predation by anglerfish and other demersal fish species (Ríos 2000, Stergiou and Karpouzi 2002) and a decrease in benthic invertebrates, their main prey species (Bozzano et al. 2005).

Results for adult hake both in the Catalan and Adriatic Sea studies suggest as well that these measures for increasing trawl selectivity may not be effective enough to allow a full recovery of highly exploited or overexploited species in the ecosystem. There is an increasing concern regarding growth and recruitment overfishing of hake in the Mediterranean Sea due to trawling and long line activities (Aldebert and Recasens 1996, Bas 2002). Adult hake, mainly caught by long line, was exposed to very high fishing mortality rates during the 1990s (Aldebert and Recasens 1996, Coll et al. 2006). To facilitate the recovery of hake populations, selectivity on bottom-trawling (mainly capturing smaller

individuals) should be improved to reduce immature catches, while fishing effort should be reduced on adult individuals (mainly captured with long lines).

## **b) Changes in total catch, landings and discards**

For the Catalan Sea, a decrease in total catches of Norway lobster, blue whiting and juvenile hake was predicted (Figure 12a). However, decreases in total catches were smaller under scenario 3, the more realistic of the 3. On the contrary, total catches of poor cod, demersal fish mixed-group (1) and adult hake increased, although the uncertainty for adult hake was higher. Generally, total catches of these commercial groups increased under all scenarios (14-28%). The overall simulations predicted a decrease in total catches by 2 to 5%, and for the last simulation that corresponds to the most realistic scenario, the reduction of total catches is by 3%. In the Adriatic Sea, total catch of Norway lobster was predicted to increase under SM\_1 and SM\_3, but the latter was associated with high uncertainty (Figure 12b). Total catch of hake was predicted not to change under scenario SM\_3, however other gadoids were seen to decrease substantially in the catch (22-50%). In general terms, total catch was predicted to decrease by 5 to 12%, the third scenario being the most realistic one and showing a decrease of total catches by 5%.

However, these reductions in total catches were notably due to a reduction in discards rather than the reduction of landings in both case studies (Figure 13), in support with results from single species analyses from the Balearic Islands (Ordines et al. 2006). In the Catalan Sea, landings were reduced by 2% and discards by 5% during the third simulated scenario, which is the most realistic of the three scenarios (Figure 13a). Discards were reduced by 14% in the Adriatic Sea and landings by 4% (Figure 13b).

Therefore, predicted results suggest that the improved trawl selectivity would have positive impacts on the catch of some target species (e.g. the demersal fish mixed-group, which includes a mixed group of demersal fish species feeding on small demersal fish and crustaceans, mainly greater forkbeard, and adult hake) in the Catalan Sea, although the catches of some other species (e.g. Norway lobster, blue whiting and juvenile hake) may slightly decrease if the present fishing effort were to be maintained. Because in the current trawl catches the mean length of hake is often under 20 cm (Sardà et al. 2006, Bahamón et al. 2006), i.e. below the minimum legal landing size, the decrease in catch of juvenile hake should not be seen as a negative result of increasing trawl selectivity. In the long run the trawl fishery would benefit from an increased selectivity (if the escaping hake survives).

## **c) Ecosystem indicators**

A significant increase in the mean trophic level of the community (TLco) (0.3-0.6%) and the mean trophic level of the catch (TLc) (0.1-0.3%) was predicted for the southern Catalan Sea (Figure 14), although the latter showed higher

uncertainty. The modified Kempton Q' index of biodiversity also increased in all three cases (16-30%).

Different studies have shown that the development of fishing is frequently related with a decrease in the mean trophic level of the community, TL<sub>co</sub>, and of the catch, TL<sub>c</sub> (Pauly et al. 1998, Jennings et al. 2002). This was described for the Mediterranean Sea, although a much lower starting value of TL<sub>c</sub> was calculated when compared to other marine areas of the world (Pauly et al. 1998). Our study suggests that the implementation of selectivity measures for trawling could contribute to a slight increase in the TL<sub>co</sub> in the southern Catalan Sea, indicating an increase in biomass of high TL organisms in line with the significant increase of Q' index. Two situations would contribute to the increase of TL<sub>co</sub>: (1) As fishing pressure on juveniles of commercial species is decreased, the biomass of exploited species is rebuilt to a certain level, and (2) by increasing trawl selectivity, fishing-induced mortality of small organisms decreases, and biomass of these species increases, so predators benefit from this situation. This would likely contribute to progress towards a higher sustainability of the fishing activity in the area (Tudela et al. 2005, Libralato et al. 2008). However, our simulations indicate as well that total ecosystem biomass ( $B_t/B_0$ ) or total fishable biomass ( $B_{f_t}/B_{f_0}$ ) would not show significant changes due to enhanced selectivity alone. This highlights the need for a more drastic decrease in fishing effort in order to rebuild the Catalan Sea and Adriatic Sea ecosystems.

### **3.3. Complementary management options to recover Mediterranean ecosystems**

Considering that results from the previous section showed that implementing measures to increase the selectivity of trawling would be positive but not enough to recover highly exploited species in the Mediterranean ecosystems, here we present the results of simple complementary management scenarios in the southern Catalan Sea to take a step forward towards more effective Mediterranean fisheries management.

#### **a) *Initial scenario: No modification of fishing effort***

Results of this scenario are used to compare with scenarios 1-3. An important increase in fishing effort from 1978 to 2003 has been recorded in the southern Catalan Sea. This has had notable impacts on the biomass of commercial and non-commercial species (Coll et al. 2005, submitted). Demersal fishes showed a significant decline in biomass in 2003 compared to levels in 1978, and their biomasses were lower in comparison with the rest of the simulations performed on management measures (Figure 15). Top predators of the ecosystem (adult hake, anglerfish, demersal sharks and large pelagic fish) also showed low biomass levels in 2003, and in general commercial biomass was lower than in the following simulations (Figure 16). On the contrary, the biomass of

invertebrates had increased from 1978 to 2003 and in 2003 (initial situation) was higher than in the rest of the simulations.

**b) Scenario 1: Increase of trawl selectivity by implementing the square-mesh codend**

In this simulation we included an increase in trawl selectivity by implementing the square-mesh codend, we took into account the effect on commercial, non-commercial species and post-escape mortality from 2003 to 2030, and compared with the initial simulation in 2003 (as previously presented in section 3.2). Simulations suggest that if in 2003 the square-mesh codend would have been implemented; there would have been higher levels of biomass for most of the commercial species such as poor cod, blue whiting, flatfishes, red mullet and anglerfish (Figure 15, simulation 1). However, Norway lobster and juvenile hake would not have shown higher biomasses due to an increase in predation mortality. In general, demersal fish biomass, commercial fish biomass and top predator biomass would be at similar levels than in 2003, while the invertebrate biomass would show a reduction (Figure 16). Overall, total catches would have decreased by 6% with respect to levels in 2003 (Figure 17a), however the total catch / total fishing mortality would increase by 10% (Figure 17b).

**c) Scenario 2: increase of trawl selectivity and decrease of total fishing effort by 20%**

This scenario implied the decrease of total fishing effort by 20% for all fleets to simulate the equivalent of a reduction of fishing effort by one day, and the increase of trawl selectivity (as in scenario 1) from 2003 to 2030 in the southern Catalan Sea. The model predicts an increase in biomass with respect to initial values in 2003 for most of the commercial species analysed, with the exception of Norway lobster and juvenile hake whose biomasses decrease due to increasing predation mortality (Figure 15, scenario 2). Top predator biomass, fishable biomass and demersal fish biomass were higher than in initial conditions of 2003 and than in scenario 1, while demersal invertebrate biomass continued to decrease (Figure 16). Overall, total catches would decrease by 18% from levels in 2003 (Figure 17a), while total catches / total fishing mortality would increase by 31% (Figure 17b). The total catch per unit of relative effort would increase as well in comparison with scenario 1 by 11% (Figure 17c).

**d) Scenario 3: increase in trawl selectivity, decrease in total fishing effort by 20%, and additional 20% reduction in fishing effort for the demersal fleets**

The last simulation performed contemplates a decrease in total fishing effort by 20% to simulate the equivalent of a reduction of fishing effort by one day for all the fleets, increase in trawl selectivity (as in scenario 1), and includes an

additional 20% reduction of fishing effort for the demersal fleets (trawling and demersal long lines) to simulate an extra day of non-fishing for these fleets from 2003 to 2030. Results showed higher increases in biomass for all commercial species analysed except for Norway lobster, juvenile hake and blue whiting (Figure 15, scenario 3). Top predator biomass, demersal fish biomass and commercial fish biomass increased with respect to the rest of the simulations, while demersal invertebrates showed a further decrease in biomass compared to all other simulations (Figure 16). Total catch was predicted to decrease by 23% from values in 2003 (Figure 17a) but total catch / total fishing mortality would increase by 61% (Figure 17b). The total catch per unit of relative effort would increase as well in comparison with scenario 1 by 46% (Figure 17c).

#### **e) Maximum projections**

Results from the simulation eliminating the fishing activity from 2003 to 2030 are represented by a line in Figures 15 and Figure 16. In the cases of flatfishes, poor cod, adult hake, anglerfish, conger eel, demersal sharks and Atlantic bonito the projected biomasses were higher than the ones predicted in scenarios 0 to 3. The biomasses of red mullet and blue whiting were always lower than the scenarios predicted due to increasing predation mortality in a recovery situation of the ecosystem. The maximum projections of biomass for Norway lobster and juvenile hake were lower than in the 2003 situation due to a low abundance of predators and thus low predation mortality. Commercial biomass is approximately 22-30% lower in all scenarios compared to the maximum projection.



## **4. Limitations**

The first part of this report presents a summary of results from single-species analyses performed in different areas of the Mediterranean to evaluate the impact of square mesh selectivity on trawling for commercial species. These studies generally demonstrate that the square-mesh codend is more selective than the diamond mesh by increasing the L50 of most target species and by reducing discards. However, it has to be taken into account that these studies only focused on commercial species and did not take into account the direct and indirect impacts of fishing on the ecosystem and other species and trophic interactions, so variations on predation mortality and post-escape mortality were not included. To assess the importance of these elements, we developed ecosystem modelling simulations that constitute the main bulk of results from this report.

While developing the ecosystem modelling simulations, we assumed that fishing mortality reduction due to increased trawl selectivity and reduction of fishing effort is constant over the simulation period. However, modifying selectivity would change the demographic structure of the population, which in turn would modify the impact of the original selectivity measures on overall mortality. This limitation is also true for previous single-species selectivity assessments (e.g. Bahamon et al. 2007a, 2007b) and ecosystem-based studies concerning the effects of improved selectivity scenarios (e.g. Kitchell et al. 2004, Criales-Hernandez et al. 2006). A more realistic study would require short-term monitoring of the fishing fleet activities and species dynamics in the ecosystem while selectivity measures are implemented. This would allow the description of dynamic fishing mortality rates that could be used to forecast ecosystem changes more accurately. Therefore, current results should be considered to be realistic only over a short time period. Moreover, we developed only simple Monte Carlo simulations and uncertainty analyses to assess ecosystem effects of selectivity scenarios in the southern Catalan Sea. We encourage future investigations to further examine the effect of uncertainty of input parameters.

These simulations, developed by applying ecosystem modelling tools, show that data on post-escape mortality is important when assessing the ecosystem effects of improved trawl selectivity. However, very little data on escape-mortality exist in the Mediterranean Sea (Figuerola et al 2001, Metin et al. 2004). Hence, the development of *in situ* studies under real commercial fishery conditions in the Mediterranean Sea for different selectivity devices and for different species is necessary. These studies should also include assessment on the vulnerability of escapees to predation after escape. Moreover, although habitat damage due to bottom-trawling could be important for some species and mitigate positive impacts of increasing selectivity, data is scarce in the ecosystem and it has not been considered in the present work.

Future experimental studies on improved selectivity should also take into account the twine thicknesses and building material of nets (Sala et al. 2007) as

well as the position and extension of the square mesh panels within the net (F. Sardà, personal communication). Selectivity experiments should be also developed during different seasons and different bathymetries to obtain a better knowledge of seasonal selectivity impacts (F. Sardà, personal communication).

Information on recruitment for most species of the ecosystem is still scarce and therefore, only information available on adult and juvenile hake was included in the ecosystem model (Coll et al. 2006). This limitation can be overcome as new ecological studies are developed. Meanwhile our results could also be compared with single-species based modelling approaches (with higher resolution on recruitment, but lower on community ecology) while performing similar scenarios of management.

In general terms, and although positive, more ecosystem analyses are needed to generalize the results on putting selectivity data into an ecological context (Coll et al. 2008). The current expansion of ecological modelling in the Mediterranean Sea and the progress on experimental work may facilitate this “to do” task in the future. Results from the ecosystem modelling that we presented here regarding the Adriatic Sea are only preliminary, since experimental data from the Adriatic were not used, but instead we used an extrapolation of the data from the Catalan Sea case study on the available model of the Adriatic Sea (Coll et al. 2007) and the same procedure than in Coll et al. (2008). These results should then be taken carefully into account.

## **5. Conclusions**

We presented a review on studies performed to analyse the impacts of increasing trawl selectivity, by changing the current 40 mm diamond mesh to 40 mm square-mesh codends. Significant numbers of experimental studies and single-species analyses are now available in the Mediterranean context, which generally give evidence that the square-mesh codend is more selective than the diamond mesh by increasing the L50 of most target species and by reducing discards. However, single-species analyses are only focused on commercial species and variations on predation mortality and post-escape mortality are not considered. Therefore, the increases on biomass and catch of commercial species are most likely overestimated in these studies.

Thus, we developed ecological simulations on the potential ecosystem impacts of this management measure to put previous data into an ecological context. Results highlight the importance of accounting not only for commercial, but also for non-commercial species and post-escape mortality, when evaluating the effects of selectivity measures. Fishing takes place within an ecosystem where target and non-target species have complex interactions, and changes in species dynamics are subjected to changes in predation mortality, competition and trophic cascades (Cury et al. 2003). Our study highlights that ecosystem impacts of improved trawl selectivity in the Mediterranean Sea are complex. However, although results from ecological modelling applications are less optimistic than those from single-species approaches, they still show noticeable effects of trawling selectivity in the Mediterranean ecosystem.

Ecosystem modelling predictions suggest that the effects of increasing bottom-trawling selectivity in the southern Catalan Sea (north-western Mediterranean) and the northern and central Adriatic Sea (central Mediterranean) would be noticeable at the ecosystem level, for both commercial and non-commercial demersal species. This is due to the complexity of trophic interactions and the direct and indirect impacts induced by fishing and mediated by the trophic web. These results have direct management applications giving support to the implementation of an improved selectivity of the bottom-trawling fleet in the area from a biological point of view. The implementation of the square-mesh codend on the Mediterranean basin would contribute towards an ecosystem-based management of fisheries in the north-western Mediterranean region.

Generally, the scientific community seems to agree that the implementation of trawling selectivity will likely have positive impacts on fishing activities due to an increase of catches of commercial species, an important reduction of discards, while there are overall no negative economic impacts for the fishing sector. However, more experiments are needed to assess technical details of implementing selectivity such as the impact of different twine thicknesses and building material of nets as well as the position and extension of the square mesh panels within the net. Selectivity experiments should be also developed during different seasons and different bathymetries to obtain a better knowledge

of seasonal selectivity impact. In any case, a close monitoring system should be implemented in parallel to the increase of trawl selectivity to validate experimental and modelling results.

Results from ecological modelling also highlight that although the implementation of selectivity devices in trawling would be noticeable in an ecosystem context, a more drastic reduction of fishing effort in parallel with a greater increase in gear selectivity would be necessary for the recovery of highly exploited or overexploited demersal species, as well as the ecosystem, to levels recorded at the end of 2003.

Thus, the alternative management scenarios that we have simulated in the southern Catalan Sea suggest that the increasing selectivity of trawl should be implemented together with a reduction of fishing effort. In this direction, we tested two alternative scenarios that considered a reduction of fishing effort by one day for all fleets (reduction of 20% of fishing effort), and reduction of fishing effort by one day for all fleets (20% reduction) plus a 20% reduction of fleet capacity of demersal fisheries. In both cases, simulations predicted higher recoveries of commercial species and vulnerable species such as top predators of the ecosystem. For commercial species, these management measures would allow the increase of biomass of several species compared to the levels registered in early 2003.

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## 7. Figures and Tables

Figure 1. The southern Catalan Sea and northern and central Adriatic Sea study areas.

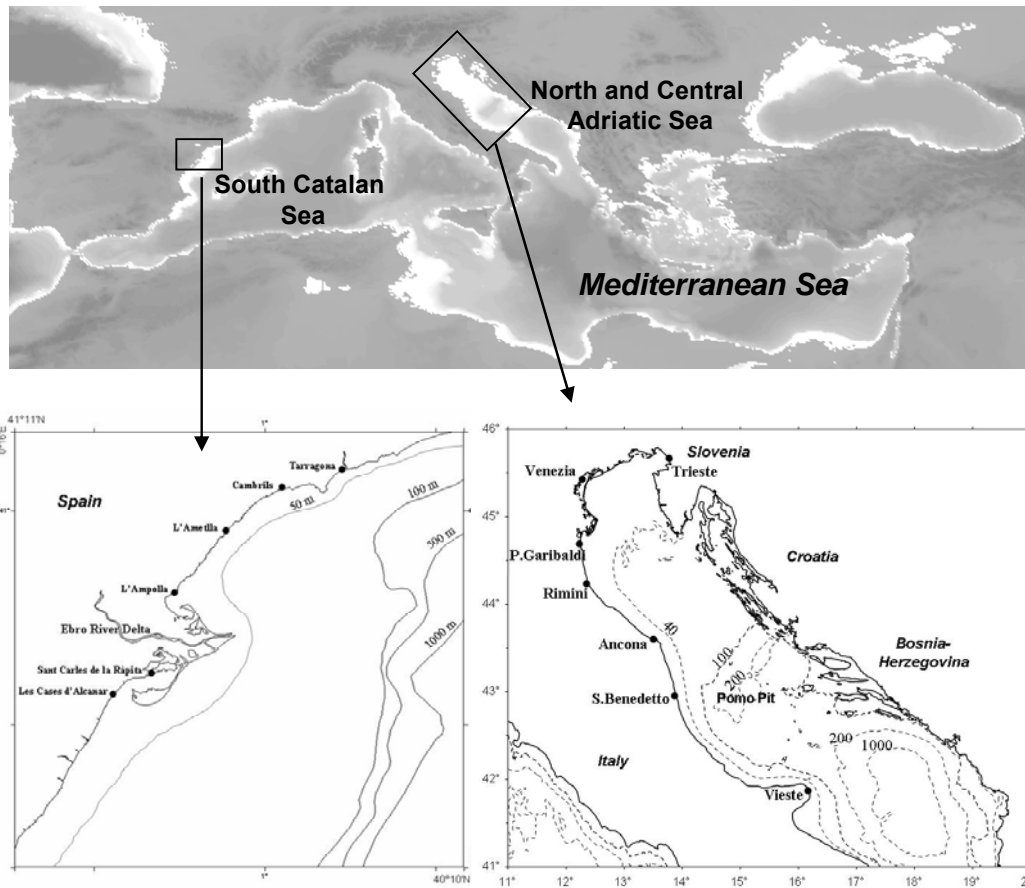
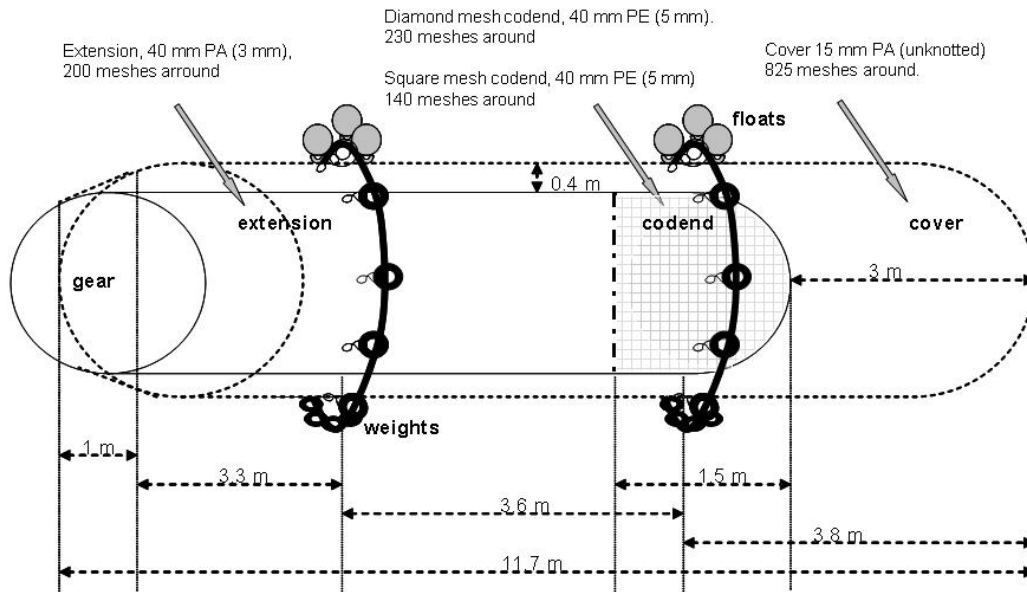


Figure 2. a) Schematic drawing of the square-mesh codend (40 mm) (modified from Coll et al. 2008) and b) implementation of the square-mesh codends during 2005 in the southern Catalan Sea (Marta Coll, 2005).

a)

### The covered square mesh codend



b)



Figure 3. Flow diagram of a) the southern Catalan Sea model and b) the northern and central Adriatic Sea model organised by functional groups and fractionated trophic levels (TL), and divided between demersal and pelagic habitats (modified from Coll et al. 2007 and 2008).

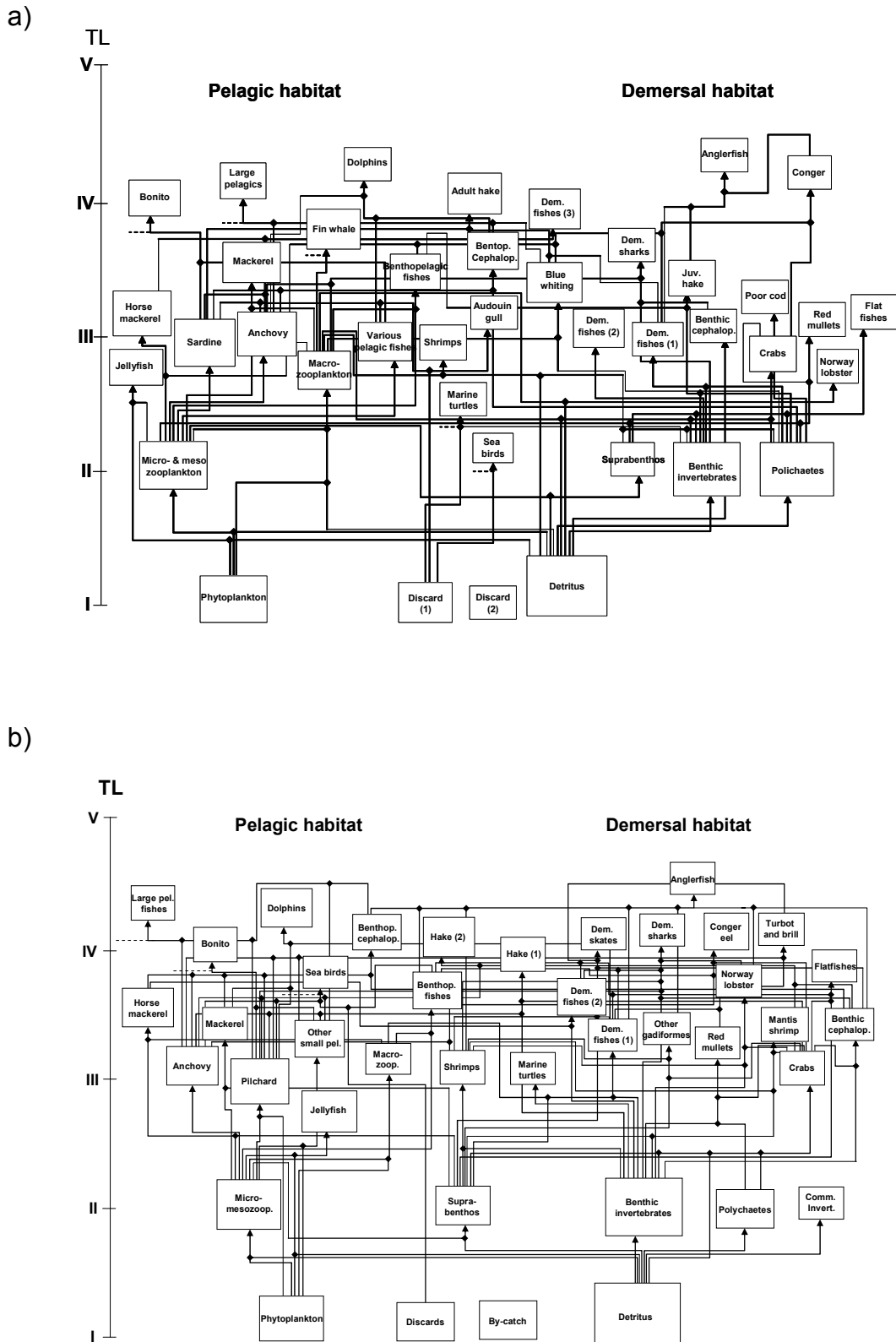


Figure 4. Examples of commercial species studied during the implementation of selectivity measures in the Mediterranean Sea (Marta Coll, 2005).



*Merluccius merluccius* – European Hake



*Phycis blennoides* - greater forkbeard



*Micromesistius poutassou* - blue whiting



*Trisopterus minutus* – poor cod



*Mullus barbatus* - red mullet



*Nephrops norvegicus* - Norway lobster



Figure 5. Comparison of selectivity curves for four commercial species caught on the continental shelf (a, b) and the upper slope (c, d) of the Catalan Sea, when using the 40 mm diamond-mesh codend (black lines) and the 40 mm square-mesh codend (grey lines) (reproduced from Bahamon et al. 2006 with permission from the authors).

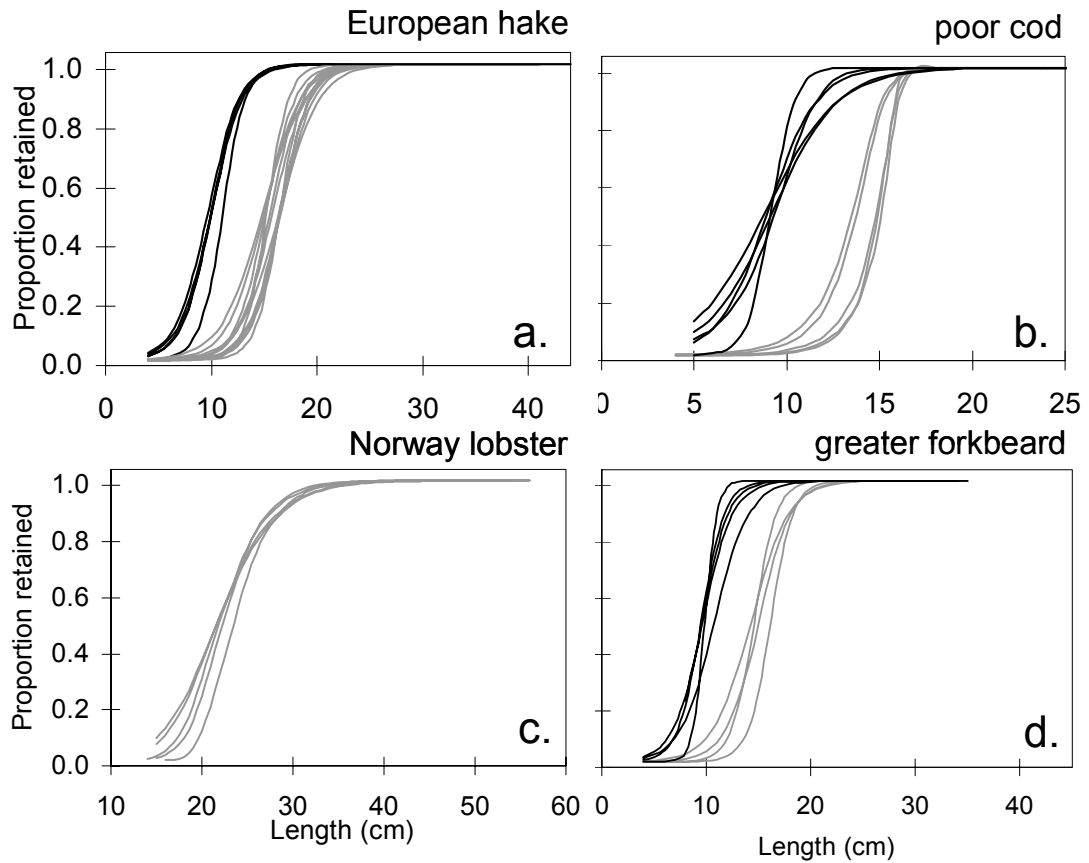


Figure 6. Evolution of yield (Y/R) per recruit for European hake (continuous thick line), poor cod (long-dash line), Norway lobster (small-dash line), and greater forkbeard (continuous thin line), after shifting from the diamond-mesh to the square-mesh codend (reproduced from Bahamon et al. 2007a with permission from the authors).

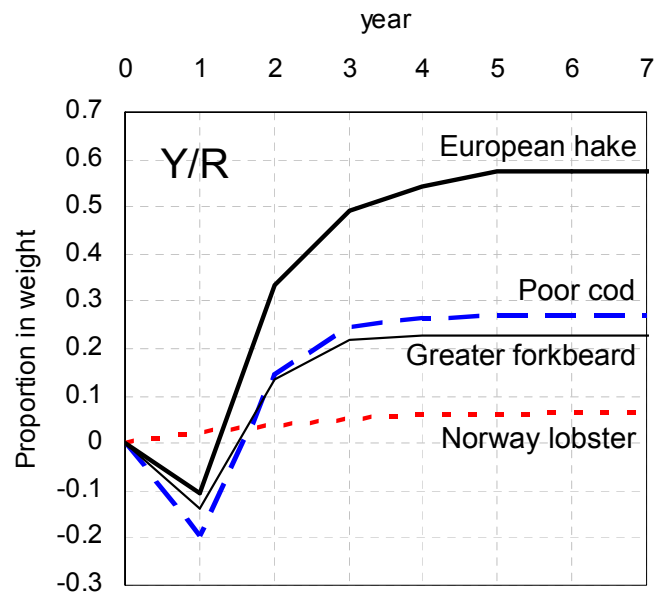


Figure 7. Mean (and standard deviation) escapement ratio, economic loss and economic efficiency for the shallow shelf (SS) and the deep shelf (DS) of the Balearic Islands (reproduced from Ordines et al. 2006 with permission from the authors). T-test results comparing mesh shape are shown (n.s.: non significant differences, \*:  $p < 0.05$ , \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ , DI: diamond mesh, SQ: square mesh).

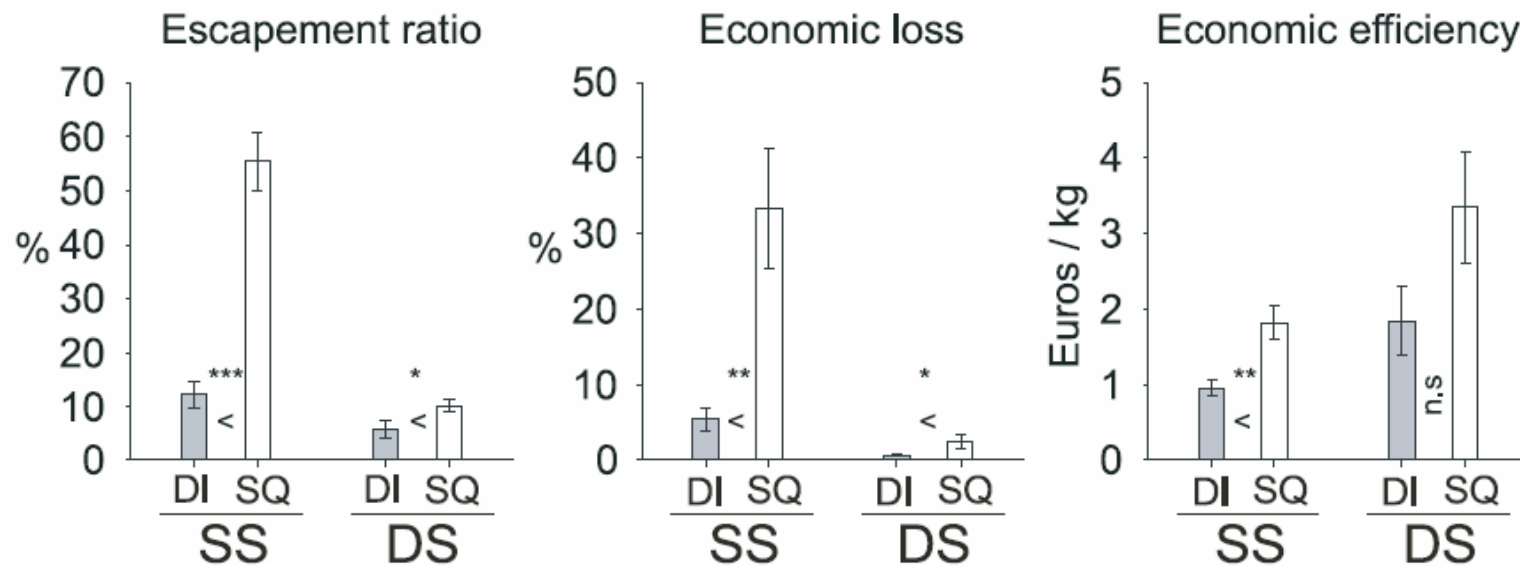


Figure 8. Mean biomass (kg 30 min<sup>-1</sup> ± S.E) of discards in total, and of principal taxa (representing >99% of total weight discarded) for the square mesh (white) and the diamond mesh (grey) (reproduced from Ordines et al. 2006 with permission from the authors). T-test results comparing the two mesh types are shown for each taxon (ns: non significant; \*: p < 0.05 and \*\*: p < 0.01). On the shallow shelf, fish discards were composed of 79.7% non-commercial species and 20.3% commercial species (4.8% *Scorpaena notata*, 4.3% *Raja miraletus*, 3.4% *Trachurus mediterraneus* and 7.8% of other species with lower importance). On the deep shelf, fish discards were composed of 90.5% non-commercial species and 9.5% commercial species (2.9% *Scyliorhinus canicula*, 1.4% *Lepidotrigla cavillone*, 1.1% *Aspitrigla cuculus* and 4.1% of other species with lower importance) (Ordines et al. 2006).

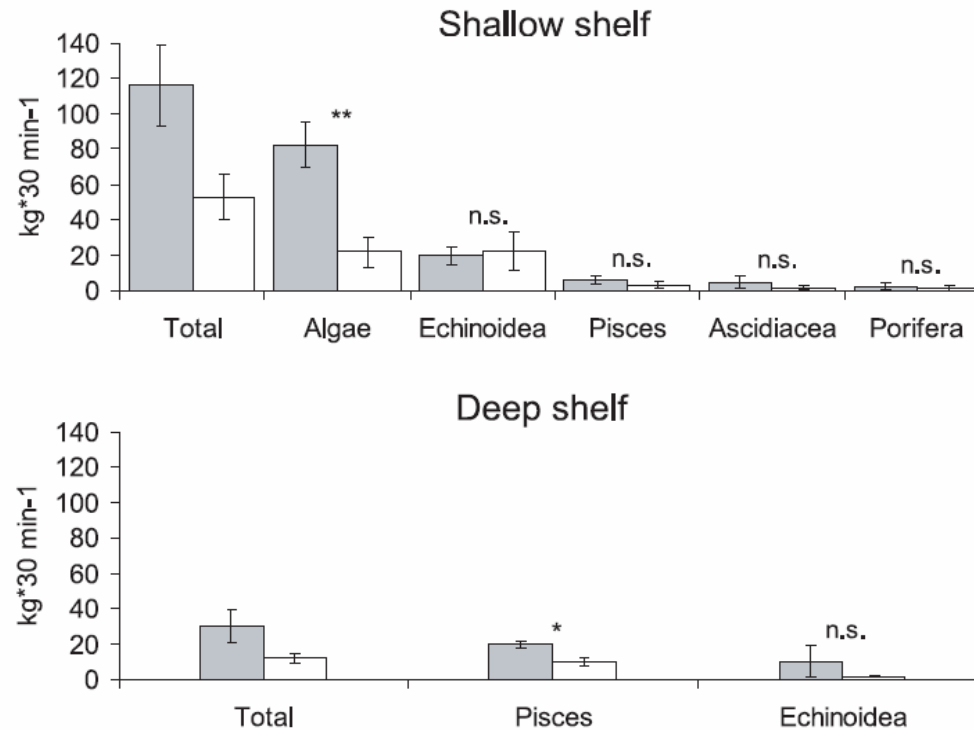
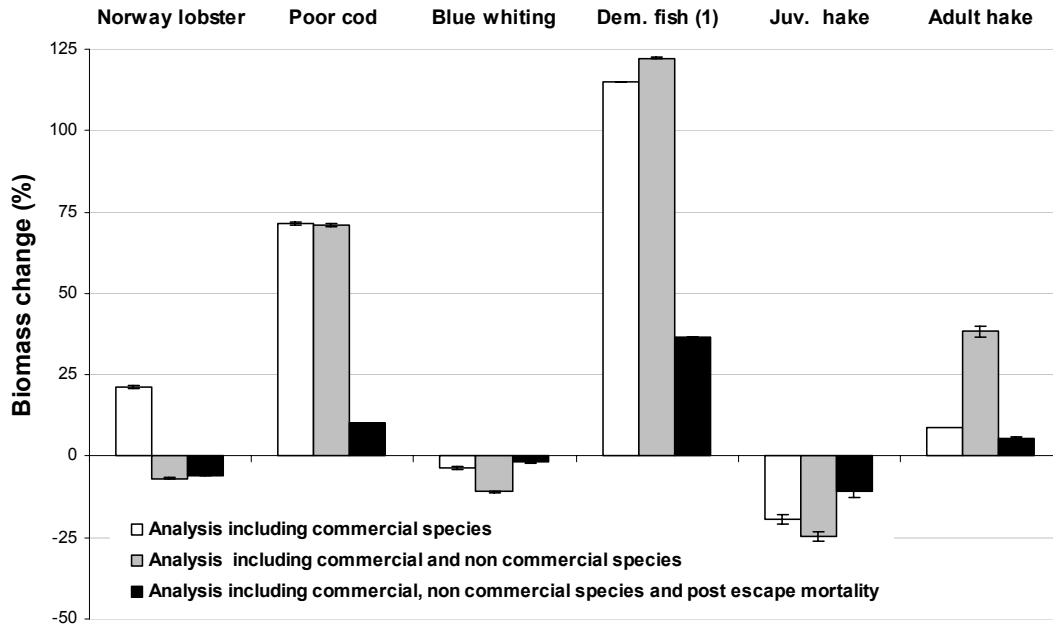


Figure 9. Change in biomass (%) of a few commercial species calculated from temporal dynamic simulations when including the square mesh (SM) in the ecosystem model of a) the southern Catalan Sea (2000-2030) and b) the northern and central Adriatic Sea. Error bars represent 1 SD around the mean.

**A. Catalan Sea**



**B. Adriatic Sea**

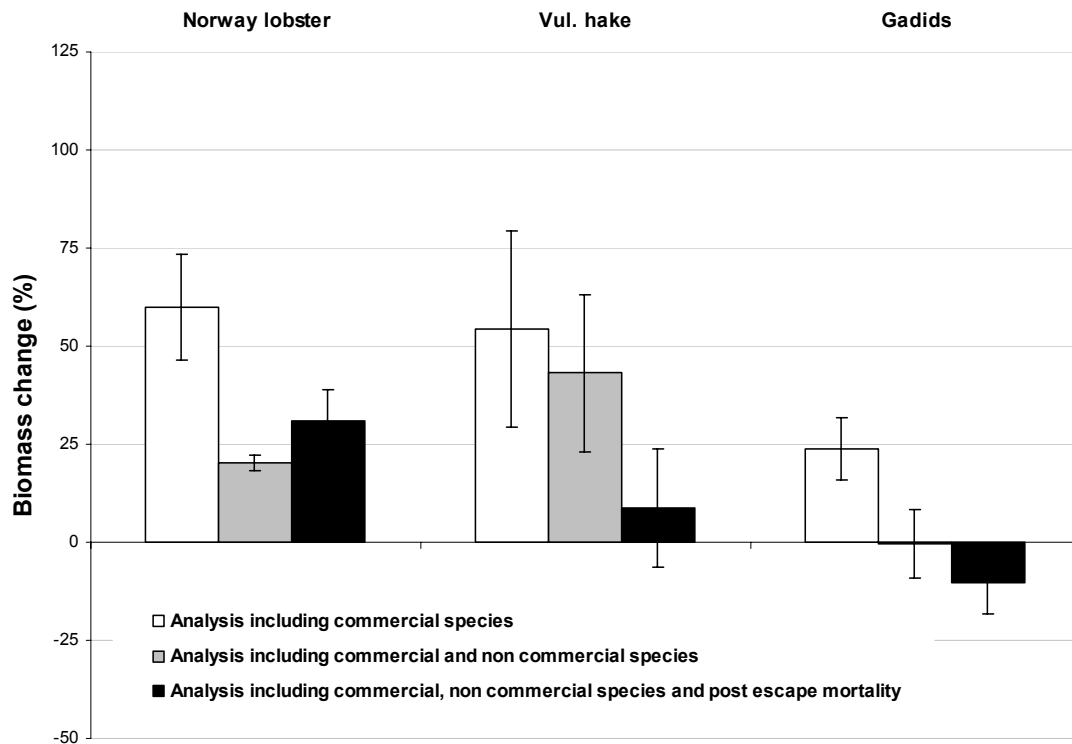
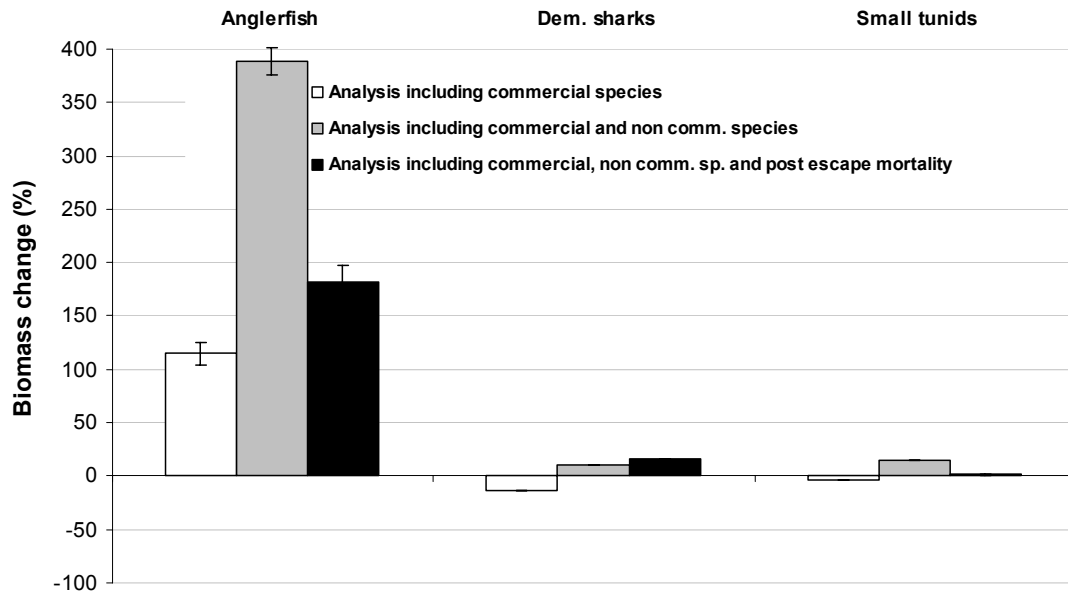


Figure 10. Change in biomass (%) of top predators calculated from temporal dynamic simulations when including the square mesh (SM) in the ecosystem model of a) the southern Catalan Sea (2000-2030) and b) the northern and central Adriatic Sea. Error bars represent 1 SD around the mean.

**A. Catalan Sea**



**B. Adriatic Sea**

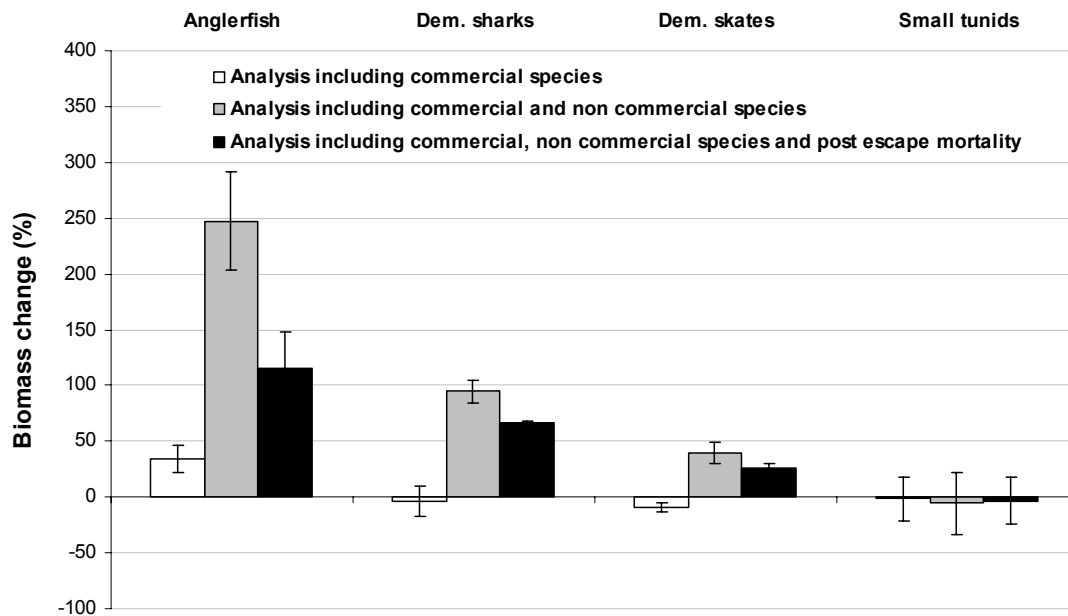
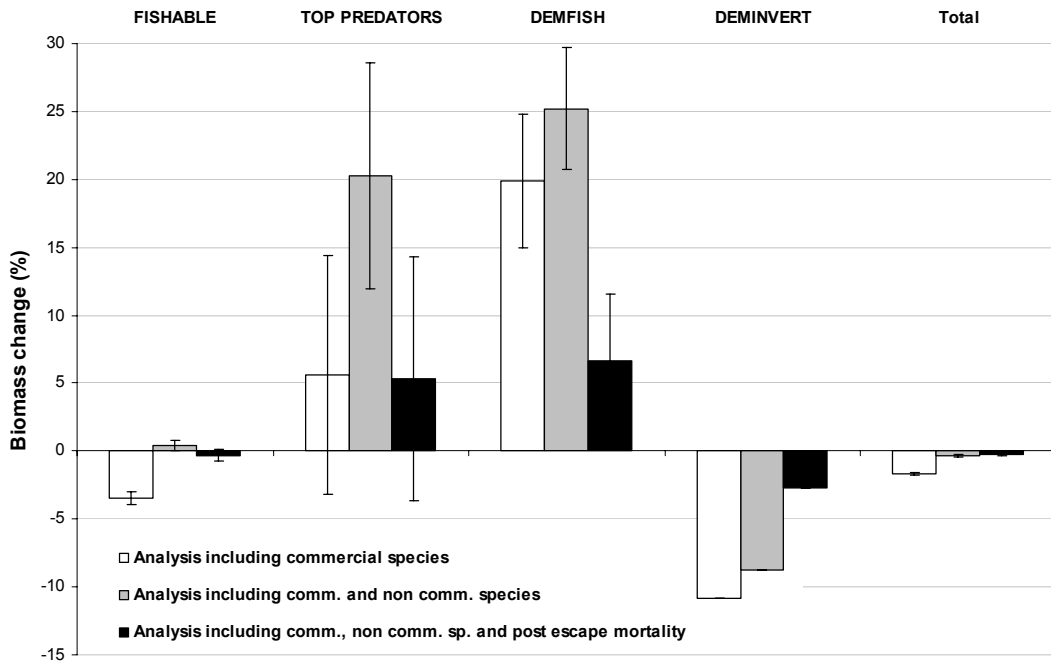


Figure 11. Change in biomass (%) of fishable organisms, top predators, demersal fish, demersal invertebrates and total biomass calculated from temporal dynamic simulations when including the square mesh (SM) in the ecosystem model of a) the southern Catalan Sea (2000-2030) and b) the northern and central Adriatic Sea. Error bars represent 1 SD around the mean.

**A. Catalan Sea**



**B. Adriatic Sea**

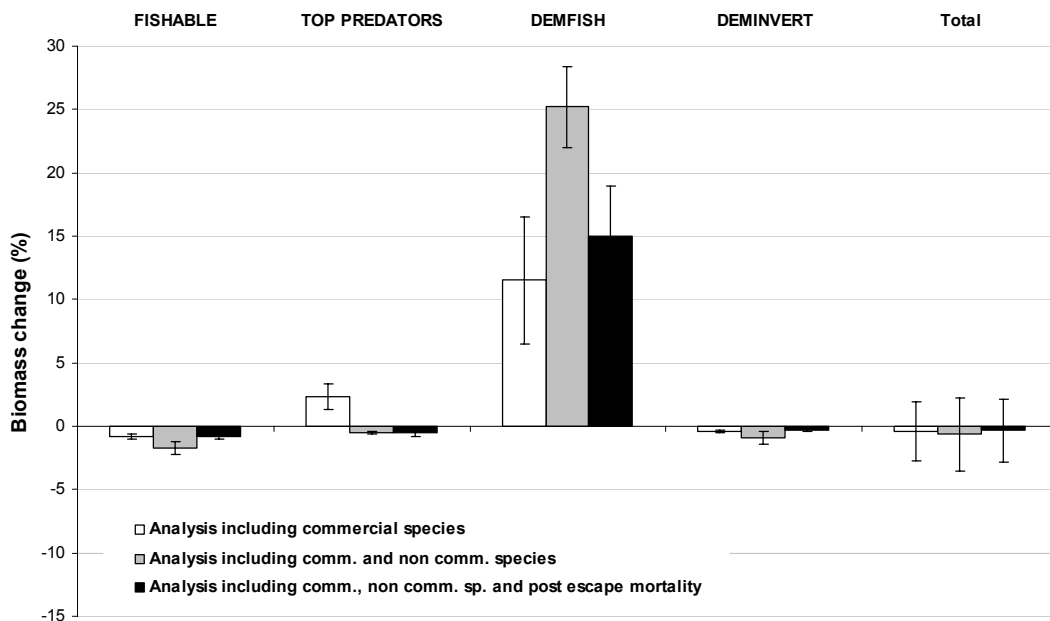
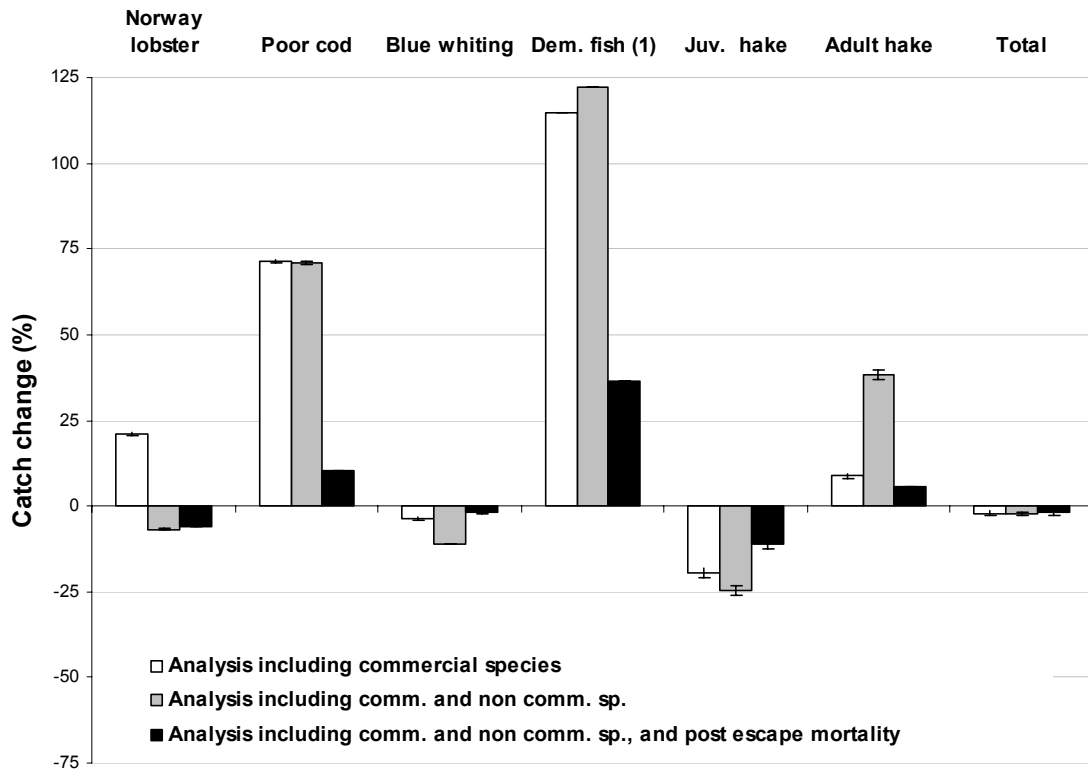


Figure 12. Change in catch (%) of few commercial species calculated from temporal dynamic simulations when including the square mesh (SM) in the ecosystem model of a) the southern Catalan Sea (2000-2030) and b) the northern and central Adriatic Sea. Error bars represent 1 SD around the mean. Total catch includes discards and landings.

### A. Catalan Sea



### B. Adriatic Sea

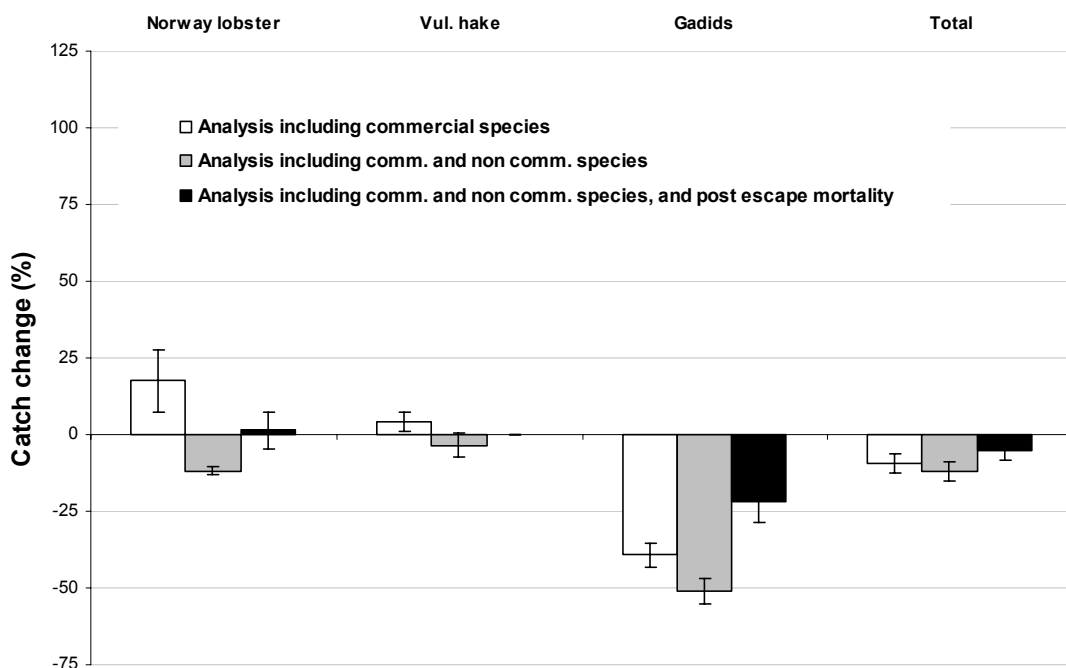
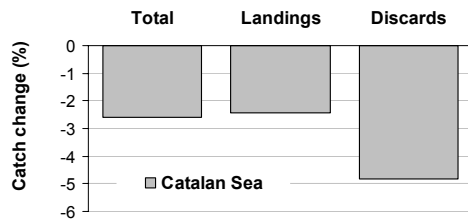




Figure 13. Change (%) in total catches, and landings and discards separately, calculated from temporal dynamic simulations when including the square mesh in the ecosystem model of a) the southern Catalan Sea and b) the northern and central Adriatic Sea, taking into account commercial and non-commercial species and post-escape mortality.

a)



b)

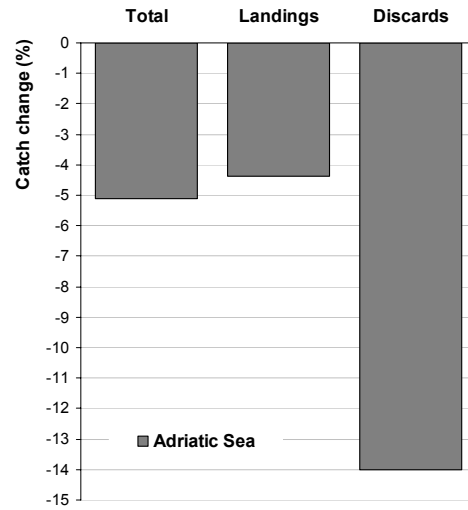
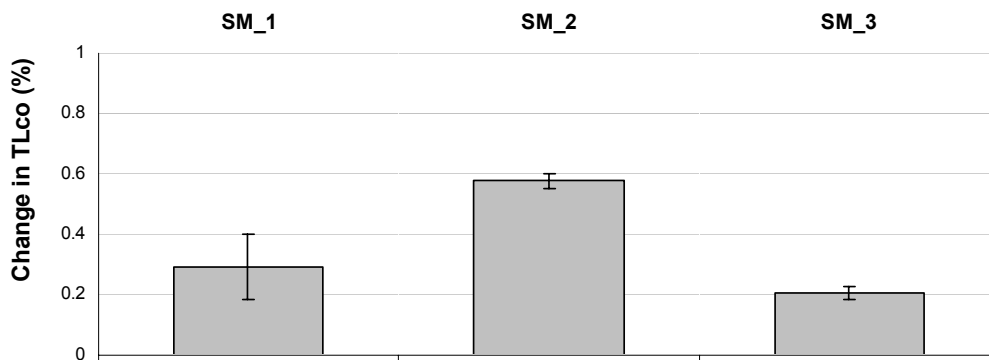
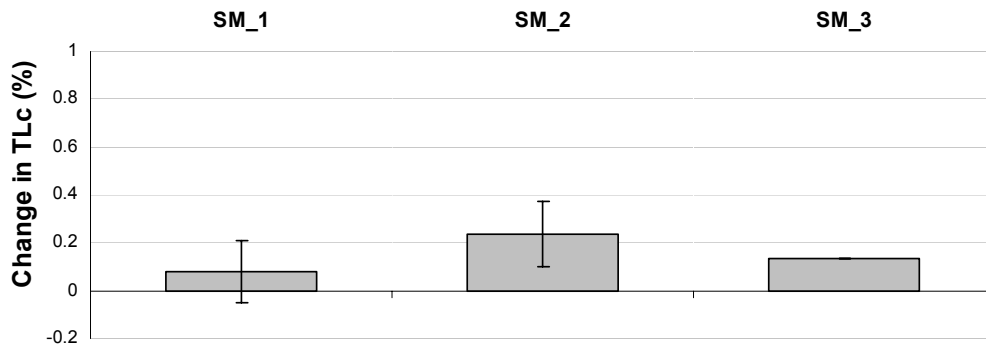


Figure 14. Changes (%) in (a) mean trophic level of the community, (b) mean trophic level of the catch, and (c) modified Kempton Q index resulting from temporal dynamic simulations (2003-2030) when including the square mesh (SM) selectivity data in the ecosystem model of the southern Catalan Sea (2003-2030). SM1 = including commercial species only, SM2 = including commercial and non-commercial species, and SM3 = including commercial and non-commercial species, and post-escape mortality. Error bars represent 1 SD around the mean.

**a) Mean trophic level of the community**



**b) Mean trophic level of the catch**



**c) Modified Q's Kempton's index of biodiversity**

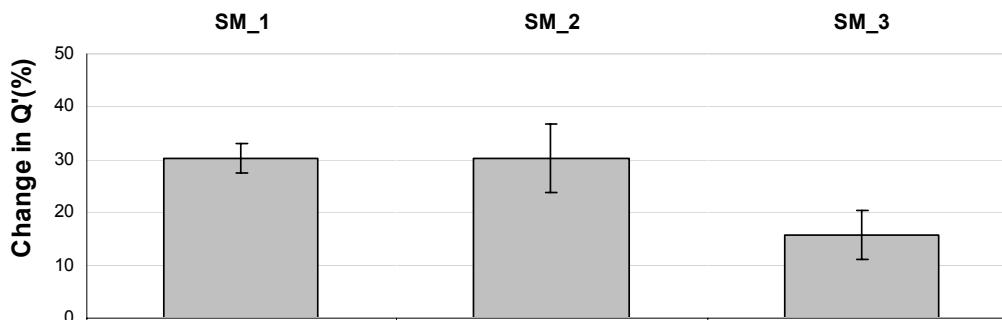


Figure 15. Biomass ( $t \cdot km^{-2}$ ) of commercial species calculated from temporal dynamic simulations for various scenarios, performed with the ecosystem model of the southern Catalan Sea (2003-2030). Initial: initial conditions in 2003, Simulation 1: including trawl selectivity, Simulation 2: Including trawl selectivity and reduction of 20% of total fishing effort, and Simulation 3: Including trawl selectivity, reduction of 20% of total fishing effort, and an additional reduction of 20% of demersal fisheries. Gross black line represents the 'maximum projection' or 'ecosystem recovery' scenario for which all fishing is eliminated from 2003 to 2030.

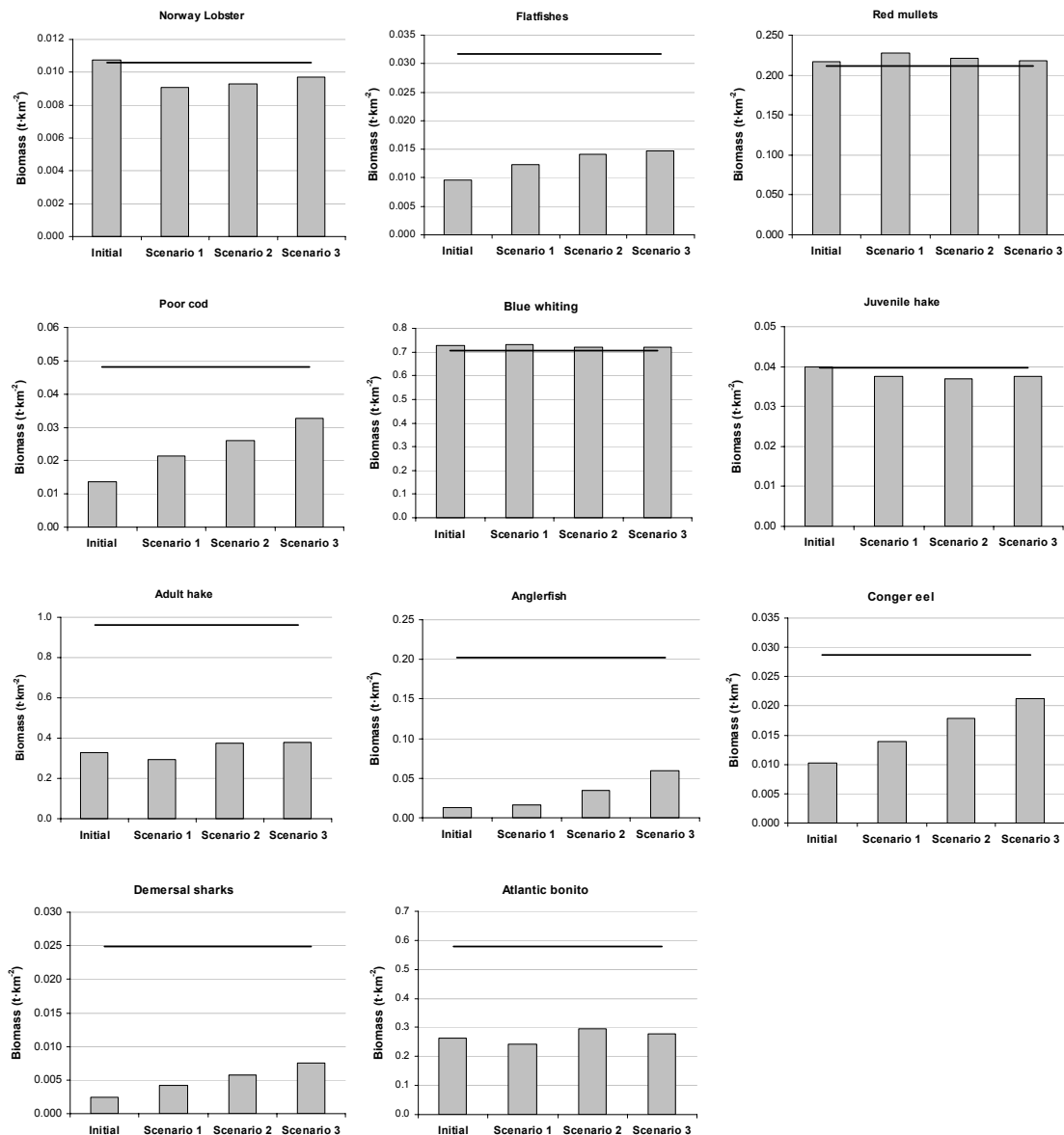


Figure 16. Biomass ( $t \cdot km^{-2}$ ) of fishable organisms, top predators, demersal fishes and demersal invertebrates calculated from temporal dynamic simulations for various scenarios, performed with the ecosystem model of the southern Catalan Sea (2003-2030). Initial: initial conditions in 2003, Simulation 1: including trawl selectivity, Simulation 2: Including trawl selectivity and reduction of 20% of total fishing effort, and Simulation 3: Including trawl selectivity, reduction of 20% of total fishing effort, and an additional reduction of 20% of demersal fisheries. Gross black line represents the 'maximum projection' or 'ecosystem recovery' scenario for which all fishing is eliminated from 2003 to 2030.

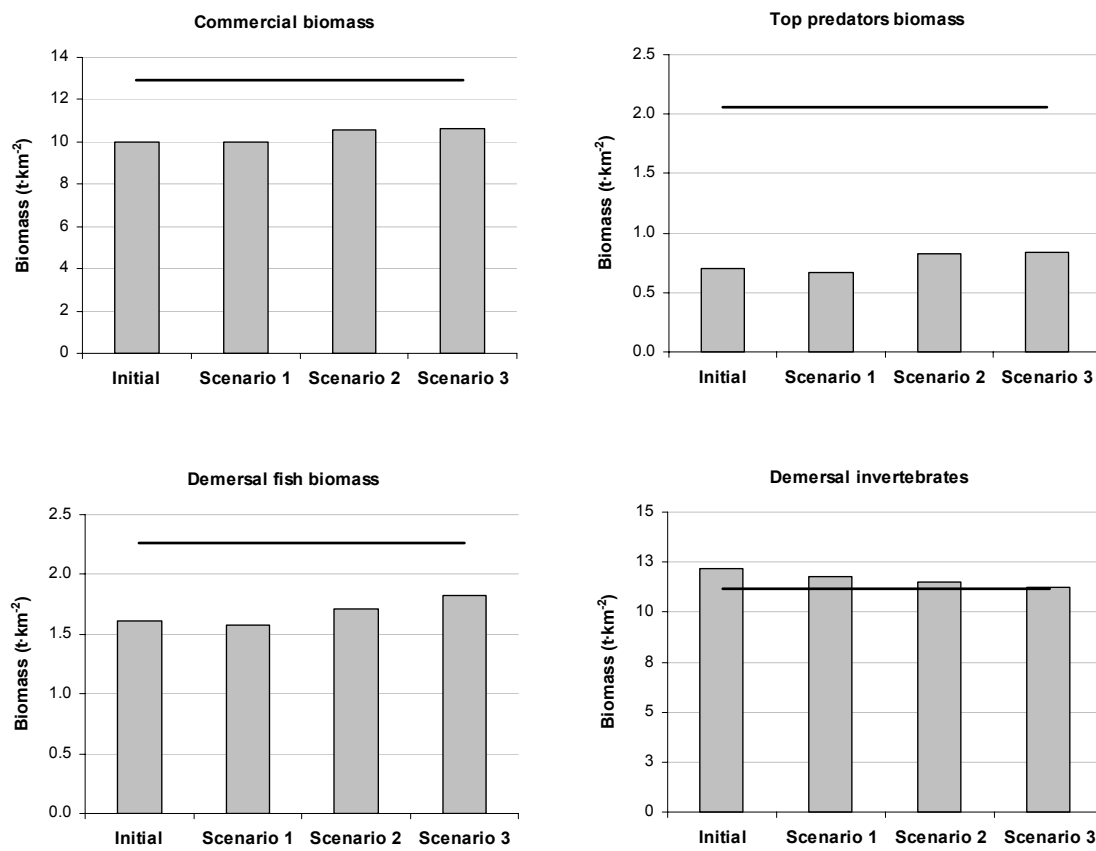


Figure 17. Changes in a) total catch ( $t \cdot km^{-2}$ ), b) total catch / total fishing mortality, and c) total catch / relative fishing effort calculated from temporal dynamic simulations performed with the ecosystem model of the southern Catalan Sea (2003-2030). Initial: initial conditions in 2003, Simulation 1: including trawl selectivity, Simulation 2: Including trawl selectivity and reduction of 20% of total fishing effort, and Simulation 3: Including trawl selectivity, reduction of 20% of total fishing effort, and an additional reduction of 20% of demersal fisheries.

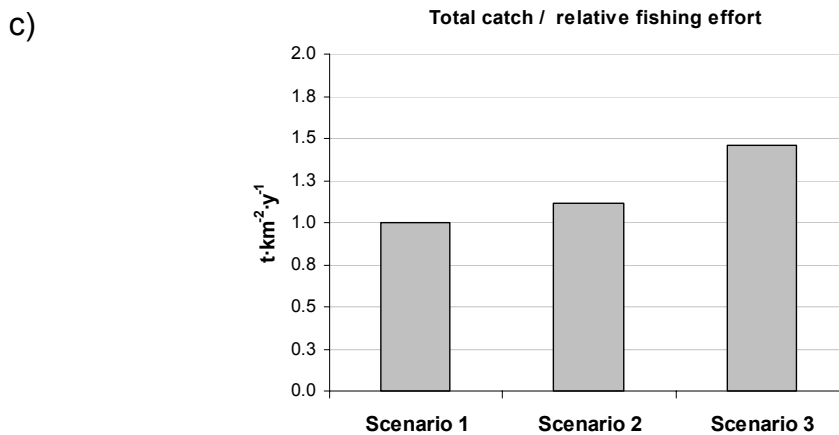
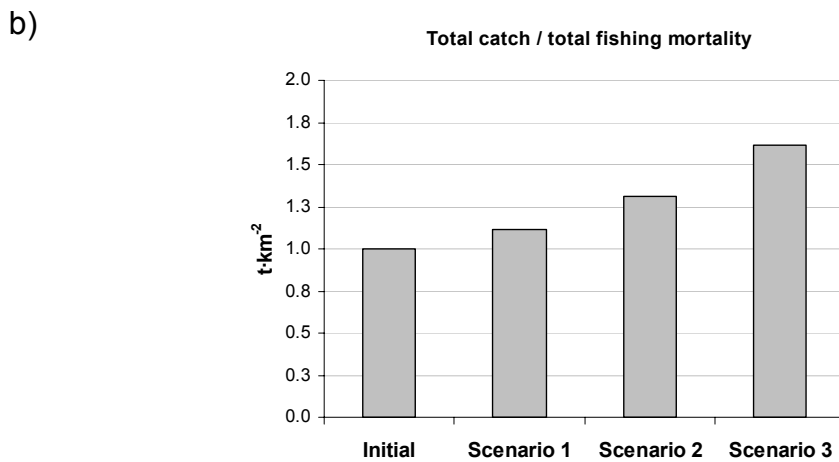
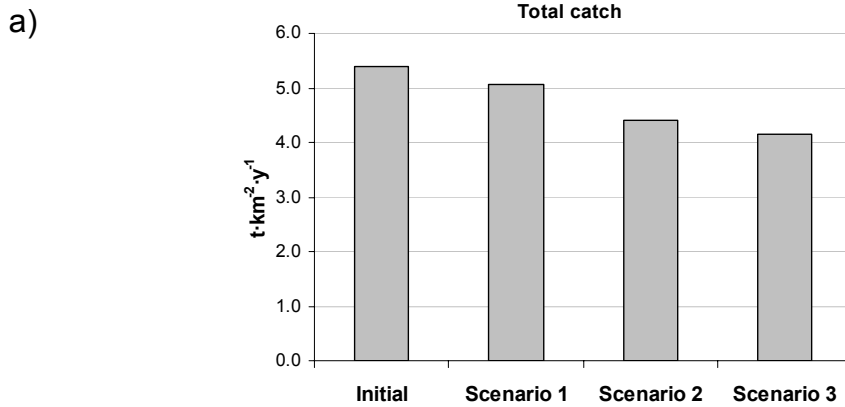


Table 1. Von Bertalanffy growth parameters ( $L_{\infty}$ ,  $K$ ,  $t_0$ ), constants (a,b) for the size-weight relationship, and maturity data used for VPA analysis (from Coll et al. 2008).

Parameters	<i>Merluccius merluccius</i> <sup>1</sup>	<i>Trisopterus minutus</i> <sup>2</sup>	<i>Micromesistius poutassou</i> <sup>3</sup>	<i>Phycis blennoides</i> <sup>4</sup>	<i>Nephrops norvegicus</i> <sup>5</sup>
<b>Growth</b>					
$L_{\infty}$ (cm)	84.8	33.3	40.4	57.7	63.9 <sup>6</sup>
$K$ (1/y)	0.135	0.180	0.220	0.168	0.160
$t_0$ (y)	-0.364	-0.910	-1.290	-0.660	-1.395
<b>L-W relationship</b>					
<b>a</b>	0.0069	0.0059	0.008	0.0012	0.0005
<b>b</b>	3.03	3.217	2.905	3.316	3.04
<b>Maturity</b>					
<b>Fertile <math>L_{50}</math> (cm)</b>	35.0	19.6	25.0	26.0	31.0 <sup>6</sup>

<sup>1</sup> Mean values for males and females in the Catalan Sea (Recasens et al. 1998)

<sup>2</sup> Mean values for males and females in the Eastern Mediterranean (Politou and Papaconstantinou 1991, Campillo 1992, Merella et al. 1997)

<sup>3</sup> Mean values for males and females in the Catalan Sea (Calderon-Aguilera 1991; Campillo 1992)

<sup>4</sup> Mean values for males and females in the NW Mediterranean (Merella et al. 1997; Froese and Pauly 2005. Fishbase database)

<sup>5</sup> Mean values for males and females in the Catalan Sea (Sardà et al. 1998).

<sup>6</sup> Units in mm.

Table 2. Reductions in fishing mortality (%) and catch (% kg) in the codend from shifting from the current 40 mm diamond-mesh codend (DM40) to the 40 mm square-mesh codend, estimated by species or ecological groups from selectivity experiments in bottom-trawling (from Coll et al. 2008).

Species	Size	Fishing mortality		Reduction (%) of catches in codend
		DM40	SM40	
<i>Nephrops norvegicus</i>	All	0.444	0.326 (-27%)	5.62
<i>Trisopterus minutus</i>	All	1.433	0.11 (-92%)	32.71
<i>Micromesistius poutassou</i>	All	0.415	0.337 (-19%)	27.53
<i>Phycis blennoides</i>	All	0.237	0.138 (-42%)	46.86
<i>Merluccius merluccius</i>	<=25 cm	0.769	0.519 (-33%)	35.57
	>25cm	0.376	0.423 (+13%)	0.00
Other species	All	0.612	0.309 (-42%)	24.72

Table 3. Estimated increase in total mortality (%) by species groups when also considering mortality caused by the trawlnet after escape (revision of data presented in Table 1 and Appendix 1) (from Coll et al. 2008).

<b>Groups of species</b>	<b>% increase in mortality</b>
Shrimps, crabs and cephalopods	15
Benthic invertebrates	50
Flatfish	30
Small demersal fish	75
Medium-sized demersal fish	40
Small and medium-sized pelagic fish	90



Appendix 1. Reviewed data used to estimate the increase in total mortality of various species when also considering the mortality caused by trawl gears after escape (from Coll et al. 2008).

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<b>MEDITERRANEAN</b>								
<i>Gobius niger</i>	Catalan Sea	1997	Small and large	88.90%	40 mm diamond mesh		Figuerola et al. (2001)	
<i>Solea vulgaris</i>	Catalan Sea	1997		28.60%				
<i>Liocarcinus depurator</i>	Catalan Sea	1997		14.30%				
<i>Medoripe lanata</i>	Catalan Sea	1997		0%				
<i>Mullus barbatus</i>	Aegean Sea	Sept. 2001	7 - 17 cm	7%	40 mm diamond mesh	24.5 - 25.5 °C	Metin et al. (2004)	Dead fish smaller than survivors. Majority of deads occurred in the first 24 h

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<b>OTHER AREAS</b>								
<i>Solea solea</i>	North Sea			40%	Beam trawl vessel		van Beek et al. (1990)	
<i>Pleuronectes platessa</i>	North Sea							
<i>Clupea harengus</i>	Baltic Sea	Spring 1991	Small and large	7-84%	Rigid grid 14 mm spacing		Suuronen (1991)	
<i>Pollachius virens</i>	Experimental			10%			Soldal et al. (1993)	
<i>Gadus morhua</i>	Experimental			0%				
<i>Melanogrammus aeglefinus</i>	Experimental			20%				
<i>Clupea harengus</i>	Northern Baltic Sea	May - June 1993	8 - 17 cm	85-90%	36 mm diamond-mesh codend		Suuronen et al. (1993)	

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
				75-85%	Rigid sorting grid 12 mm bar spacing			
<i>Melanogrammus aeglefinus</i>	Experimental			50-70%	155 mm diamond mesh		Jonsson (1994)	
<i>Coregonus albula</i>	Lake Puulavesi	July-August 1993	5 - 10 cm	30-40%	24 mm square mesh trawl	13 - 20 °C	Suuronen et al. (1995)	
<i>Merlanogrammus aeglefinus</i>	NW coast of Scotland	Summer 1993	16 - 37 cm	33-52%	70 mm diamond mesh cod-end		Sangster et al. (1996)	Smaller fishes showed higher mortalities
				18-21%	90 mm diamond mesh cod-end			
				22-27%	100 mm diamond mesh cod-end			

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<i>Merlangius merlangus</i>	NW coast of Scotland	Summer 1993	17 - 36 cm	11-15%	110 mm diamond mesh cod-end			Smaller fishes showed higher mortalities
				40-48%	70 diamond mesh cod-end			
				22-27%	90 mm diamond mesh cod-end			
				23-33%	100 diamond mesh cod-end			
				14-17%	110 mm diamond mesh cod-end			

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<i>Clupea harengus</i>	Northern Baltic Sea	April to June 1992	<12 cm	72%-91%	Diamond mesh of 26 and 36 mm	5 - 10 °C	Suuronen et al. (1996a)	Mortality was high size-dependent
			12 - 17 cm	30%-62%	Diamond mesh of 26 and 36 mm			
<i>Clupea harengus</i>	North Baltic	May - June 1993	<12 cm	76-96%	Rigid sorting grid 12 mm bar spacing	3 - 10°C	Suuronen et al. (1996b)	Data expressed for 7 and 14 days after capture
		October - November 1993	12 - 17 cm	44-77%	Rigid sorting grid 12 mm bar spacing			
			<12 cm	100%	36 mm diamond-mesh codend			

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
			12 - 17 cm	83-100%	36 mm diamond-mesh codend			
<i>Gadus morhua</i>	Southern Baltic sea	May - June 1994	24 - 50 cm	<1%	95 mm exit windows	9.5 °C	Suuronen et al. (1996c)	
<i>Gadus morhua</i>	Northern Norway	1993 - 1994	1 year old	Minimal	diagonal metal grid	4 - 6 °C	Soldar & Engaas (1997)	
<i>Melanogrammus aeglefinus</i>			2 year old	Minimal	diagonal metal grid			
<i>Merlangius merlangus</i>			3 year old	Minimal	diagonal metal grid			
Various fishes	Gulf of Carpentaria	November 1993		Higher	Diamond-mesh codend 45 mm		Farmer et al. (1998)	Study in terms of mechanical damage

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
				Higher	Square mesh of 38 mm			Species studied: <i>Sardinella albella</i> , <i>Saurida micropectoralis</i> , <i>Arius thalassinus</i> , <i>Apogon poecilopterus</i> , <i>Carax bucculentus</i> , <i>Leiognathus splendens</i> , <i>Lutjanus malabaricus</i> , <i>Pomadasys maculatum</i> , <i>Upeneus sulphureus</i> , <i>Pseudorhombus arsius</i>
				Minimal	Square mesh of 45 mm			

Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<i>Merlanogrammus aeglefinus</i>	Barents Sea	2000 - 2001		26.2 - 50.4%	Codend		Ingolfsson et al. (2002)	
				1.6 - 20%	Sorting grid			
<i>Gadus morhua</i>				0%	Codend			
				0%	Sorting grid			
<i>Pollachius virens</i>				0%	Codend			
				0%	Sorting grid			
<i>Theragra chalcogramma</i>	Kodial Island, Alaska	May - June 1998	24 - 36 cm	47 - 85%	Square mesh	6 - 8 °C	Pikitch et al. (2002)	Pelagic trawl. Mortality was highly size-dependent.
				47 - 63%	Extension-square mesh			



Appendix 1 cont'd

Species	Ecosystem	Year	Sizes/ages	Mortality rates	Selectivity device	Water Temperature	Reference	Observations
<i>Gadus morhua</i>	Baltic Sea	1997 - 1998	12 - 45 cm	>3%		< 10°C	Suuronen et al. (2005)	120 mm diamond-mesh codend, Danish type 105 mm escape window codend, 105 mm square mesh top-panel codend
				75%		>15°C		

Appendix 2. Reviewed data on implementation of square mesh codend on trawling in the Mediterranean Sea. L50 : 50% selection length.

Region	Selectivity device	Year	Species	Results	Reference
<b>Balearic Sea</b>					
Southern Catalan Sea	40 mm square mesh codend	July 2005	European hake, Norway lobster, poor cod and greater forkbeard	Higher L50	Bahamon et al. 2006
Southern Catalan Sea	40 mm square mesh codend	July 2005	European hake, Norway lobster, poor cod and greater forkbeard	Lower Y/R in short terms but higher in 5 years	Bahamon et al. 2007a
Balenaric Islands	40 mm square mesh codend	2002-2003	Deep sea crustaceans and fish	Higher L50, lower discards, higher escapement, economic loss and efficiency, lower discards	Guijarro and Massutí 2006
Balenaric Islands	40 mm square mesh codend	2002-2003	Shallow and deep water fish and invertebrates	Higher L50, lower discards, higher escapement, economic loss and efficiency, lower discards	Ordines et al. 2006

Appendix 2 cont'd

Region	Selectivity device	Year	Species	Results	Reference
<b>Alboran Sea</b>					
North of Alboran	40 m square mesh codend	2003-2004	From shallow (60m) to deep (500m) water fish and crustaceans: hake, blue whiting, red mullet, cephalopods and shrimps	Higher L50, higher escapement, no sig. loss in fishing yields	Baro and Muñoz de los Reyes 2007
<b>Adriatic Sea</b>					
Central Adriatic Sea	39 mm square mesh codend	September 2004	Shallow waters (15-21 m, 70 m) species: squid, hake, red mullet, Norway lobster, common pandora, deepwater rose shrimp, horse mackerel, poor-cod and flatfish.	Higher L50 and higher escapement for all species with the exception of flatfish	Sala et al. in press.
<b>Aegean Sea</b>					
Trikeri Channel and Euboikos Gulf	40 mm square mesh codend	October and March 1993	Shallow to deep waters, hake, blue whiting, poor cod and flatfish	Higher L50 and higher escapement for all species	Petrakis and Stergiou 1997
Turkish and international waters	40 mm square mesh codend and higher	October 1995	Shallow waters between 30 - 110 m for red mullet, annular sea bream and axillary sea bream	Higher L50 and higher escapement for red mullet, no significant for the rest	Tokaç et al. 1998

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