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Monitoring the *Prestige* oil spill impacts on some key species of the Northern Iberian shelf

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Abstract

Selected key components of the continental shelf benthic and demersal communities were monitored for the two years following the *Prestige* oil spill (POS) in order to identify the possible ecological effects of the oil. This work includes the first results regarding changes in abundance, distribution and food habits of hake (*Merluccius merluccius*), four-spot megrim (*Lepidorhombus boscii*), Norway lobster (*Nephrops norvegicus*) and Pandalid shrimp (*Plesionika heterocarpus*) populations of Galician and Cantabrian Sea shelves following the POS.

Significant reductions in the abundance of Norway lobster, *Plesionika heterocarpus* and four-spot megrim were detected in the POS maximum impact area, located over the Galician shelf. Noteworthy recoveries were observed in the 2004 abundance indices of four-spot megrim and *Plesionika*. On the other hand, no significant effects were detected in the abundance or distribution of hake juveniles even though the tar aggregates were bound by the same oceanographic drift events as the hake recruits were during the winter of 2003 (*Navidad* current) in different water column layers of the Cantabrian Sea. Feeding patterns of the four species analysed did not present apparent modifications that can be related to the POS.

Keywords: *Prestige* oil spill; Cantabrian Sea; Galicia; Food web; Hake; Four-spot megrim; Norway lobster; Pandalid shrimp; Tar aggregates

1. Introduction

The oil spill resulting from the accident of the oil tanker *Prestige*, initially during the towing operation (14–18 November 2002) and later during the breaking-up and sinking of the vessel 250 miles from the Galician coastline (19 November 2002), released about 50,000 tonnes of drifting heavy oil (type M-100) in an oceanic area and in the continental shelf waters off Northern Spain. In general terms, most of the surface of the northern Spanish shelf (Cantabrian Sea and Galician waters, $\sim$30,000 km^2) was affected. This shelf includes unique habitats and communities, high biodiversity and species richness, and important fisheries (OSPAR, 2000; Sánchez and Olaso, 2004). During the first phase, the oil floated on the sea surface affecting organisms that inhabit the upper water layers (plankton, seabirds, etc.). Due to the rough winter weather conditions following the oil spill and the wave action, the oil might also have been mixed to a certain depth within the water column, where sensitive organisms may have been exposed and affected. Finally, a spill of this nature involves the deposition of oil in particulate and aggregate form on the sea floor, where it can also affect the benthic ecosystem. A particular characteristic of the *Prestige* oil spill (POS) is the large area and variety of habitats affected, covering tidal and subtidal levels to oceanic and bathyal habitats. The effects of oil spills on fisheries resources and marine communities have been well documented at tidal and subtidal levels (Dauvin, 1998; Gómez-Gesteira and Dauvin, 2000; Peterson et al., 2001, 2003), however scarce information is available on possible effects offshore, in deep shelf and bathyal communities.

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A research project supported by the Spanish Science and Technology Ministry based on a multidisciplinary approach was designed to monitor the possible ecological impacts of the POS on continental shelf ecosystems and their fisheries resources. The aim of the study was to assess the possible effects of the oil through different basal ecosystem compartments and the trophic cascade of those effects to other compartments, such as those at high trophic levels. Assessment of these cascading effects through the food web is especially important if we take into account that, due to the particular productivity of Galician waters and the Cantabrian Sea (OSPAR, 2000; Sánchez and Olaso, 2004), the area affected by the POS includes important fisheries (200,000 tonnes per year), which directly or indirectly support the economies of many communities along the coast.

The design of the monitoring project involved sampling the different compartments of the benthic and demersal ecosystems in the area and studying the feeding patterns of several crustaceans and demersal fish species. Nevertheless, considering the economic importance of the fisheries operating in the area and the fact that the possible impacts on this particular ecosystem may have medium or long-term effects like those documented in earlier oil spills (Peterson et al., 2003), we conducted detailed studies on some economic and ecologically key species to determine the effect of the POS on their populations. Three criteria were used to select these species: (i) a wide distribution and sufficient abundance to permit efficient data collection; (ii) behaviour exposing them to high chronic biological exposure; (iii) species for which a considerable historical time series is available from the surveys regularly conducted in the area, allowing the assessment of the possible effects of the oil spill through the pre-and post-oil spill comparison. The key species selected were demersal fish that range into deep water, such as hake (*Merluccius merluccius*) and four-spot megrim (*Lepidorhombus boscii*), and the crustaceans Norway lobster (*Nephrops norvegicus*) and the Pandalid shrimp (*Plesionika heterocarpus*).

European hake (*Merluccius merluccius*) is the main target species of the ground fisheries in the north of Spain. Nowadays, the spawning stock biomass (SSB) is below safety limits and landings in the north of Spain have reached their lowest historical levels ($\sim$3500 t year^{-1}) due to overfishing. This unstable situation, in combination with likely exposure to sublethal doses of toxic hydrocarbons, compromising possible health, growth and reproductive effects, requires special monitoring in order to be able to explain the possible consequences for the hake population in coming years. Adults are at a high trophic level (Sánchez and Olaso, 2004) and it is now probably too early to detect any effects from the oil spill, but juveniles, mainly the 0 year class, feed on suprabenthic detritivorous organisms (Velasco and Olaso, 1998, 2000), which are the first to receive toxic detritus. Also, the main shelf area affected by the POS coincides with the main nursery of the southern stock of hake (Casey and Pereiro, 1995; Sánchez and Gil, 2000).

Four-spot megrim (*Lepidorhombus boscii*) is another noteworthy target species of the trawl fishery in the north of Spain (about 1000 t year^{-1} in the last decade). Annual variability in population parameters is relatively stable when compared to other fish species inhabiting the area. This flatfish lives on muddy grounds of the middle and outer shelf, at 100–300 m depth (Sánchez et al., 1998) and therefore in areas in which there is greater bioavailability of PAHs, given oil exposure, due to the presence of organic matter in sediments. This fish feeds mainly on detritivorous crustaceans (Olaso and Rodríguez-Marín, 1995), has low migratory capacity (Sánchez et al., 1998) and has previously been identified as sensitive to PAHs in the NW Mediterranean Sea (Pietrapiana et al., 2002).

Decapod crustaceans in general occupy a lower trophic level than fish in soft-bottom marine communities, as their diets are more closely linked to the exploitation of benthic organisms, detritus of different origins, and carrion (e.g. discarded fish). Mud and foraminiferans are usually found in stomach contents of a number of species. Therefore, decapods were considered to be important target taxa for the following objectives: (1) to measure the occurrence of oil in stomach contents of species, and (2) to test the correlation between the occurrence of oil in the environment and the degree of stomach fullness of these species. Among decapods, two target species were chosen, Norway lobster due to its economic importance, and the Pandalid shrimp *Plesionika heterocarpus* because, in spite of its secondary interest as a commercial species, it is the dominant and most widely distributed decapod in the trawlable area. In addition to its mainly benthos-based diet, Norway lobster is also characterised by its territorial behaviour associated with burrowing, a behaviour which could make this species particularly sensitive to the accumulation of hydrocarbons on the sea bed.

Cascading indirect effects can be as important as direct trophic interactions produced by oil spills, but current risk assessment models used to project possible biological injuries to marine communities ignore these indirect effects, treating species populations as independent of one another (Peterson et al., 2003). Food webs represent an essentially static account of the natural history and structure of trophic interactions, which can suggest potentially important direct and indirect links among component species (Peterson et al., 2001). The present work is a first account of the initial monitoring of the POS impacts and attempts to understand the effects on species and fisheries through ecosystem dynamics, which summarise the trophic interactions in space and time enabling a glimpse into long-term responses and recovery processes.

2. Material and methods

2.1. Survey design and data analysis

The data on species abundance and distribution come from the historical series of bottom trawl surveys carried out every autumn in the area from 1983 to 2004 using standardised methodology (ICES, 1999). These surveys follow a stratified random sampling scheme (Fig. 1) with three depth strata (70–120, 121–200 and 201–500 m) and five geographical sectors (MF, FE, EP, PA, and AB). The number of hauls per stratum was proportional to its trawlable surface and the sampling unit was made up of 30-minute hauls at a speed of 3.0 knots, using the baca 44/60 otter trawl gear (Sánchez, 1993; ICES, 1999). A mean of 120 hauls per survey were carried out, a sampling size that provides a high level of spatial coverage and comprises most of the areas of distribution of key demersal and benthic species in the area (Fig. 1). For each haul, catches in weight and in number of all individuals and length distributions by sex for key species were obtained. Also, a fixed number by length-class of otoliths of hake and four-spot megrim were extracted to determine age, and age–length keys were built for each survey.

In addition to this time series, new surveys were carried out after the POS, at the end of 2002 and in the springs of 2003 and 2004. These surveys, carried out on board the R/V *Cornide de Saavedra* and *Vizconde de Eza*, followed a multidisciplinary approach covering depths of between 70 and 500 m and following 23 fixed stations over the Galician shelf (Fig. 2). In this new survey series, different sampling gears were used with the aim of collecting as many samples and as much information as possible immediately after the oil spill (Serrano et al., 2005, this volume).

The stratified mean catch per trawl hour was used as the abundance index, following the methodology described by Grosslein and Laurec (1982). The stratified mean and variance are, respectively,

$$\text{Stratified mean catch} = \overline{Y}_{\text{st}} = \frac{1}{A}\sum A_{\text{h}}\overline{y}_{\text{h}}$$

and

$$S^2_{\overline{Y}_{\text{st}}} = \frac{1}{A^2}\sum \frac{A_{\text{h}}^2 S_{\text{h}}^2}{n_{\text{h}}}$$

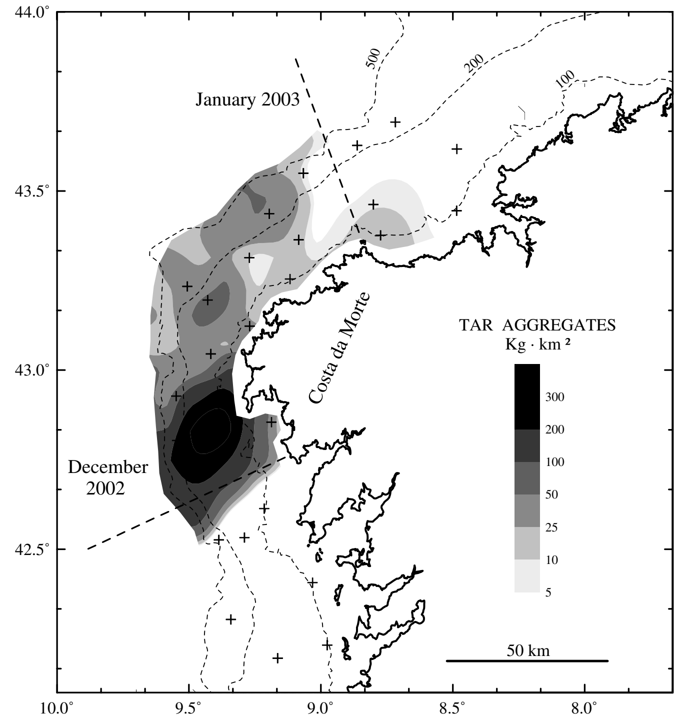

Fig. 2. Distribution of *Prestige* tar aggregates amounts on the sea floor (kg km^{-2}) one month after the accident (December 2002–January 2003). Zone of maximum impact considered for some analysis is between dashed lines.

where A is the total area surface; A_{h} is the surface of stratum h; y_{h} is the mean catch per haul in stratum h; n_{h} is the number of hauls in stratum h and S_{h}^2 is the variance in stratum h.

2.2. Fish feeding habits

In order to study possible changes in hake and four-spot megrim related to the POS, we compared data of stomach contents from autumn 2000 in the maximum impact area

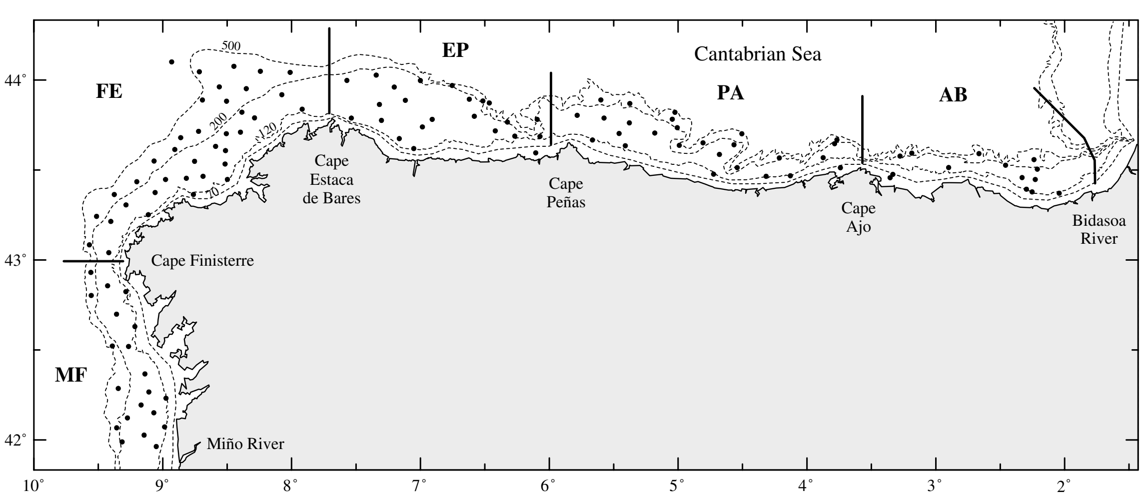

Fig. 1. Standardized survey stratification and location of sampling stations during the 2003 survey in Northern Spain.

(sector FE in Fig. 1) with those from 2003. Stomach contents analysed during the surveys carried out in winter 2002, and the springs of 2003 and 2004 were not considered so as to avoid bias due to the seasonal variation in their feeding habits. In each haul, a minimum of 10 individuals from each age class of each fish predator species were randomly selected to analyse their stomach contents (age class 1: 10–17 cm, age class 2–3: 18–24 cm, and age class 4+: >24 cm in four-spot megrim, age 0 was not analysed since it is made up of individuals smaller than 10 cm, which are too scarce to provide representative samples; age class 0: ⩽16 cm, and age class 1+: >16 cm in hake). For each predator, length was measured to the lower cm and stomach fullness was then classified as 'with food', 'empty' or 'regurgitated'. In addition, the state of the gall bladder was used (Robb, 1992) in all fish to determine possible regurgitation (especially common in hake). Stomachs containing food that had been ingested during the haul itself (i.e. the gall bladder was not used) were considered empty.

The total stomach content volume (cc) of fish with food was measured using a *trophometer* (Olaso et al., 1998). Prey were identified to the lowest possible taxon in the case of fish and decapod crustaceans; other invertebrates were classified to a higher taxonomic level. The percentage of the total stomach content volume was noted for each prey type. Stomach content weight was derived from a regression model between the volume estimated and the actual weight of the stomach contents (Olaso, 1990).

Diet composition was studied using percentage in weight of the stomach contents (Hyslop, 1980). Two variables were used to evaluate yearly differences in feeding activity: (i) the mean stomach content weight estimated using the regurgitated correction factor (Hislop et al., 1991; Velasco and Olaso, 1998), in the case of hake; and (ii) differences in the percentage of empty stomachs. The significance of the differences between years was tested using the χ^2 test and the Shannon–Wiener diversity index was used to determine the degree of feeding specialisation of each predator group, estimating bootstrap confidence intervals for this index to allow a comparison between years by randomly re-sampling the original stomach samples using the number of stomachs of the minimum sample size of those compared. This methodology (Hall et al., 1990; Labropoulou et al., 1999) allows a better comparison in the case of different sample sizes, although it can result in both confidence intervals of the larger sample being smaller than the actual diversity value in the sample.

2.3. Decapod crustacean feeding habits

Specimens were collected during the two spring surveys, 17–26 April 2003 and 24 March–11 April 2004. In the absence of pre-spill decapod crustacean diet data, diets was compared between hauls in which oil aggregates occurred and hauls in which they did not. Specimens were measured (CL, cephalothorax length, mm) and weighed (wet weight, 0.001 g precision) individually. A total of 42 specimens (practically all individuals captured during the 2003 cruise) of Norway lobster and 616 (278 from 2003, and 338 from 2004) of *Plesionika heterocarpus* were dissected and stomach contents were analysed under a stereomicroscope (×10–×40). No specimens were found to contain any traces of oil in stomachs. Nor were traces of oil found in the mouth appendages of specimens dissected.

Diets were established on the basis of specimens containing some food in their stomachs (21 Norway lobster and 97 *Plesionika heterocarpus*). Due to their scarcity in the environment, the analysis of Norway lobster diet was restricted to some comparisons between individuals captured in oiled hauls (10 specimens analysed) and non-oiled hauls (11) on the bottom. Due to the small sample size, analysis of fullness trends was rather limited for this species. The number of species per haul was between 10 and 18 for *Plesionika heterocarpus* for diet analysis, and between 16 and 30 for fullness trends.

A mean fullness (WW of stomach content/WW of specimens) with the corresponding 95% C.I. was calculated by haul. Possible correlations between stomach fullness and oil density in the environment (non-parametric Spearman *r*), quantified using a beam trawl, were calculated. There were only five cases for Norway lobster and 24 for *Plesionika heterocarpus*, after combining both surveys for this latter species. Weight of prey in diet was estimated by applying the points method (Swynnerton and Worthington, 1951), which consists of giving a series of points to each prey as a function of its dominance in each foregut content (100 points for the main prey) after visual estimation under the stereomicroscope.

3. Results

3.1. Heavy oil on the shelf

The POS oil degradation and the descent of oil particles and tar aggregates through the water column led to the presence of oil in the benthic habitat, the consequences of which are unpredictable. The quantity and distribution of the macroscopic heavy oil residues (Photograph 1) was quantified using a 3.5 m beam-trawl, originally designed for sampling deep benthic communities (Sánchez, 2003; Serrano et al., 2005, this volume), allowing estimates of the degree of the impact and contributing to a better definition of the oiled and non-oiled areas. Given that the studies available to date on the presence of PAHs in the sediment point to a chronic situation rather than the effects of the POS (Soriano et al., 2003), the present study assumes that the area of greatest impact corresponds to that defined by the presence of tar aggregates on the bottom one month after the catastrophe. This is an area in Galicia off the Costa da Morte, with maximum densities of 300 kg km^{-2} at depths of around 150 m (Fig. 2). This spatial pattern of the impact over the continental shelf of Galicia was confirmed by the results of the later surveys carried out in the area, although densities reduced progressively due to

Photograph 1. Appearance of tar aggregates found in deep grounds of the continental shelf (Sánchez).

natural burial processes (Serrano et al., 2005, this volume). Nevertheless, it must be mentioned that as a result of the drift of large oil slicks towards the interior of the Bay of Biscay, considerable quantities of tar aggregate were also found over the Cantabrian Sea continental shelf in March 2003 (Fig. 3), with greater incidence in the eastern part (sectors PA and AB).

3.2. European hake

The part of the hake population that is accessible to the methodology of our surveys corresponds mainly to juveniles, since the adults live largely in non-trawlable hard grounds of the continental slope (Sánchez et al., 2002). The hake recruitment indices of the five years previous to the POS (1998–2002) were at very low levels, consistent with the low level of adults (spawning stock), which were at their lowest level in the historical series (Fig. 4). The two years following the POS show a slight recovery of the strength of recruitment, although values remain low in the context of the historical series.

When the *Prestige* accident occurred, the hake year class had already passed its pelagic phase and was recruited to the bottom of the continental shelf, as shown by the results of the survey in October 2002 (Fig. 5a). This situation, one month before the POS, was abnormal with respect to previous years, since the main hake nursery, normally on the continental shelf of the Finisterre–Estaca sector (FE of Fig. 1) had failed, but good recruitments (>1000 individuals h trawl) had, nevertheless, been found in the south of Galicia (sector MF). One year after the catastrophe, distribution patterns of recruits were consistent with those obtained throughout the historical series, with a greater presence of recruits in sector FE (Fig. 5b). These recruits (11–17 cm length), which were in their pelagic larval stage during the season in which the oil slicks were drifting over the continental shelf, did not apparently suffer any alterations to their presence and distribution at the bottom.

Hake diet composition in the post-spill survey was similar to that found in the surveys carried out in the two previous years for both age 0 and age 1+ (Table 1). The most characteristic prey for age 0 hake were euphausiids and shrimp among the crustaceans and small fishes such as silvery pout or horse mackerel. For age 1+ (nekton feeders) the main prey was blue whiting (*Micromesistius poutassou*). An apparent change in the post-spill survey (2003) was the increase in the number of prey taxa for both age class groups, and therefore in the diversity index of diets (Fig. 6). Nevertheless, according to the results of the confidence intervals estimated through the bootstrap methodology, this change seems to be related with the larger sample size in 2003 (Table 1), since the diversity index was greater for this year but the confidence intervals are overlapped by those of the previous years. Neither in the mean stomach content nor in the emptiness percentage (Table 1) were there any recurring trends in 2003 compared to the two previous years. The mean stomach content was slightly

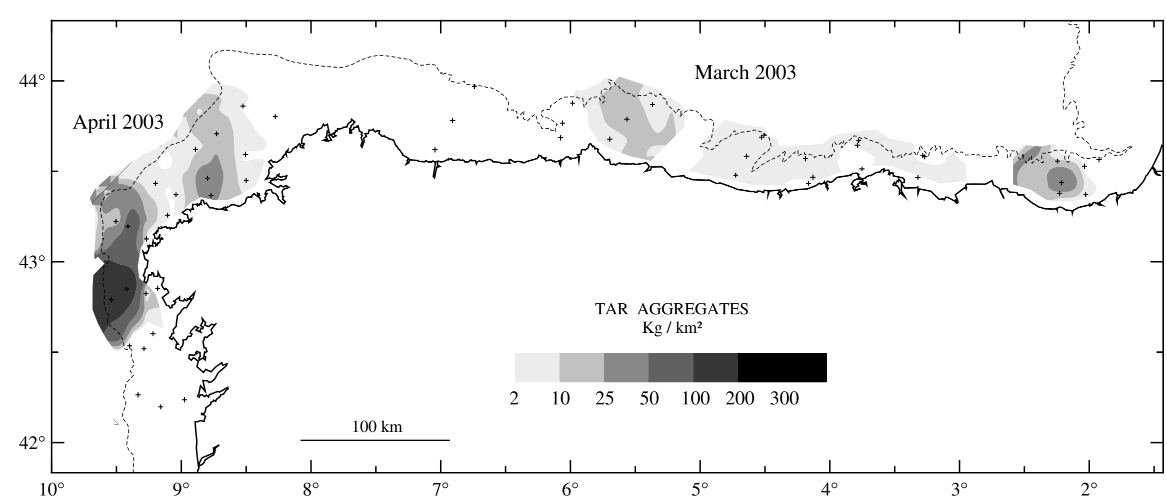

Fig. 3. Distribution of *Prestige* tar aggregates amounts on the sea floor (kg km^{-2}) during spring 2003. Data from 3.5 m beam trawl survey.

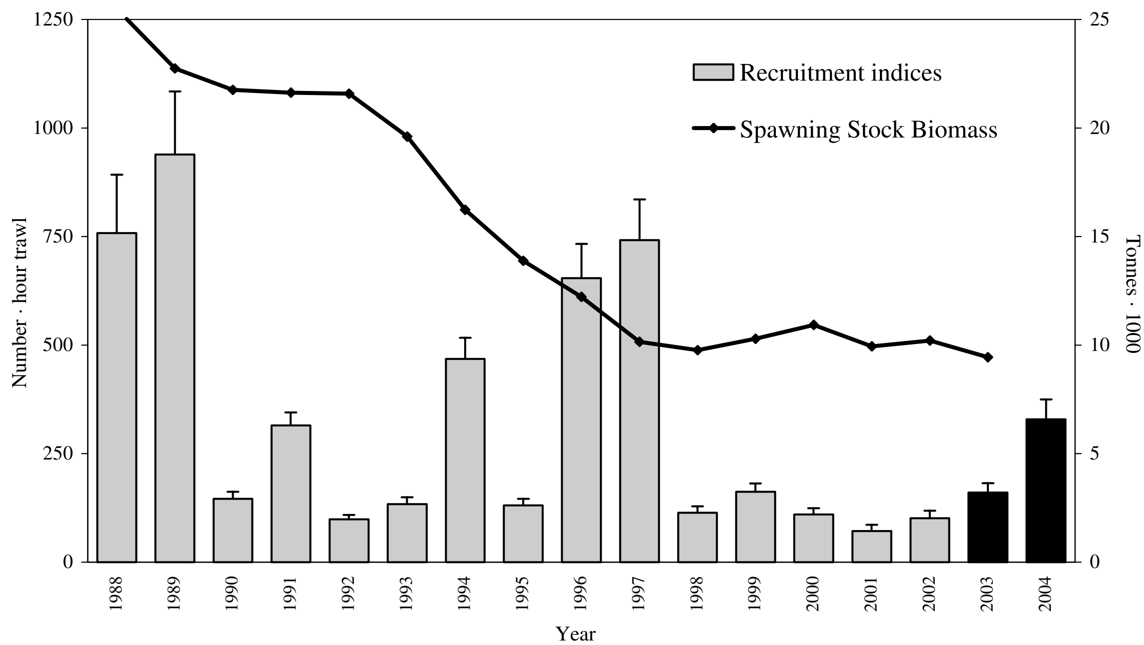

Fig. 4. Historical series (1988–2004) of stratified mean densities of hake recruits (number hour trawl ± SE) from surveys and spawning biomass of southern stock (tonnes · 1000) from ICES 2004.

lower in 2003 than in the two previous years for the age 0 group, while for the age 1+ group the 2003 value was in the middle of the range. The percentage of empty stomachs in 2003 was also between the 2001 and 2002 values for both age groups. The differences are statistically significant only for the age 0 group ($\chi^2_2 = 28.6$, $p < 0.01$), but the intermediate position of the 2003 value suggests that these differences are not related to the POS.

3.3. Four-spot megrim

Survey indices show a significant decline in abundance in the year following the POS to a level clearly below the minimum inter-annual variability observed in the last decade (Fig. 7). Nevertheless, the 2004 survey shows a recovery to the mean values of recent years. The spawning stock biomass of the southern stock is low but relatively stable in the pre-spill decade (Fig. 7). Survey indices by age class (Fig. 8) indicate moderately strong cohorts for 1999 and 2000 as shown by the abounding age class 1 found in both the 2000 and 2001 surveys (the gear has poor access to age class 0). On the other hand, the 1998 and 2001 cohorts can be considered poor. Taking into account that most of the population accessible during the surveys is made up of individuals of 1, 2 and 3 years, the 2001 cohort does not seem to be the only one responsible for the low abundance index of the species in the 2003 survey, since individuals aged 1 and 3 do not amount to what might be expected of their respective cohorts either (Fig. 8). The year-class distribution from the 2004 survey indices shows a very strong 2003 cohort and a recovery of the 2001 and 2002 year classes, which contradicts the low values detected in 2003.

The spatial distribution patterns of megrim juveniles do not appear to show any alterations clearly related to the area of maximum impact of the oil spill (off the Costa da Morte) given that the decreased abundance of this species is uniformly distributed throughout the area. Nevertheless, this decrease has been more apparent throughout the continental shelf of Galicia and the western area of the Cantabrian Sea than in the eastern area, where the decline is much less evident (Fig. 9).

As with hake, no clear or noteworthy differences between pre-and post-spill diet compositions are apparent in four-spot megrim (Tables 2 and 3). This predator consumes a wide variety of benthic and supra-benthic prey, crustaceans preferably, but fish also play an important role in their diet at older ages. After the accident of the *Prestige* (2003 survey), the percentage of supra-benthic crustaceans, euphausiids, and mysids increased in the diet of the younger age groups (age 0 was not analysed), mainly replacing some decapod preys especially at age 1. At this age the increase was more pronounced. The rest of the changes in the diet composition in 2003 compared with the previous surveys are not consistent between the different age groups, and do not result in any outstanding changes when compared to the variability found in the previous years. Fig. 6 shows the diet diversity index time series by age group between 2000 and 2003 (2000 is excluded for age 4+ due to the small sample size). Diet diversity in 2003 was within the variability found in previous years for all age groups.

Statistically significant differences in the percentage of empty stomachs were found for age group 2/3 ($\chi^2_3 = 10.7$, $p = 0.013$) but no such differences between years were found for age group 1 ($\chi^2_3 = 3.7$, $p = 0.3$) and age 4+ ($\chi^2_2 =$

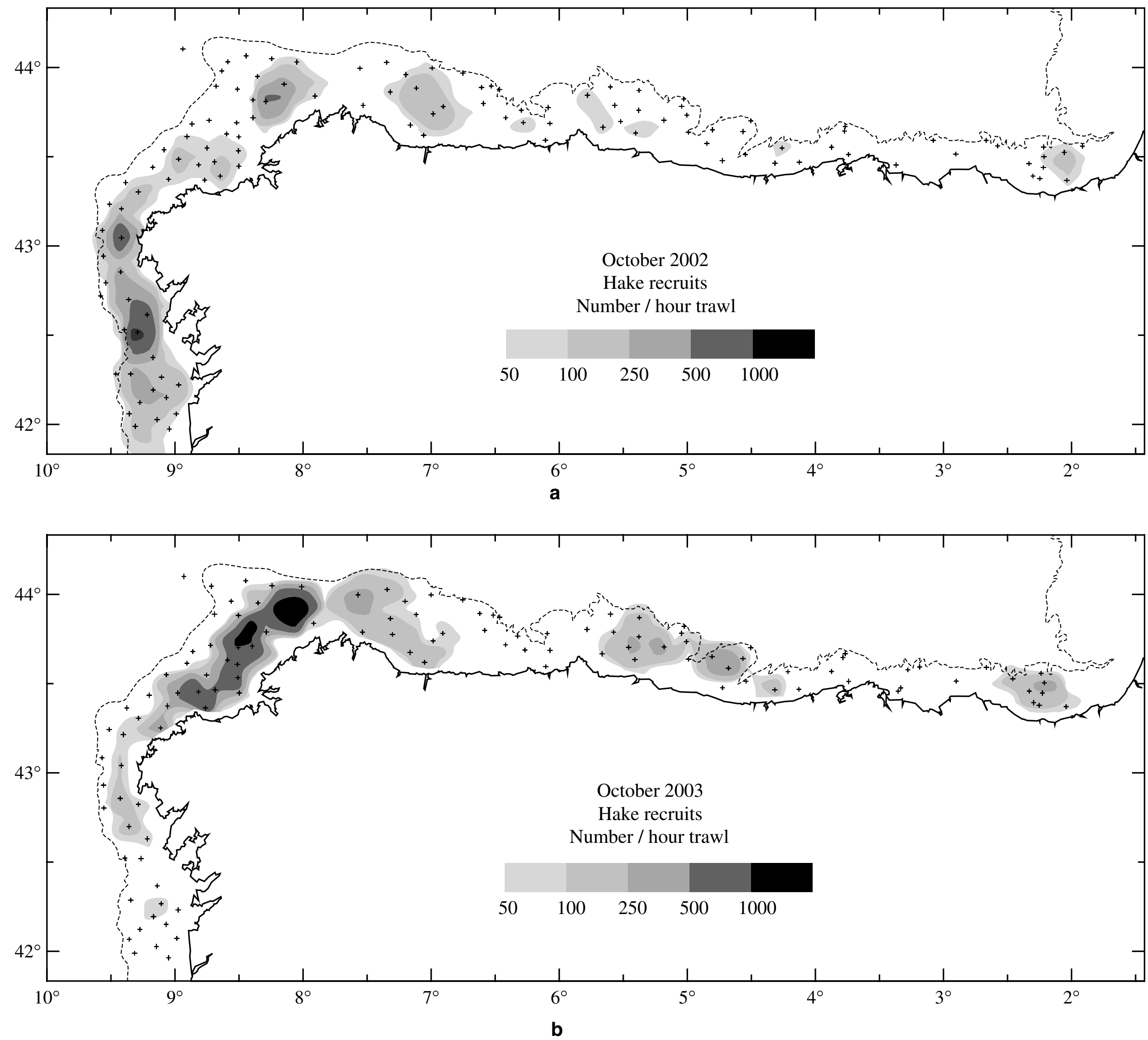

Fig. 5. Spatial distribution of hake recruits from surveys before (a) and after (b) the *Prestige* oil spill (2002–2003). Density contours from geostatistical analysis (*kriging* and spherical model).

3.8, $p = 0.15$). Regarding mean fullness (also shown in Tables 2 and 3), there are statistically significant differences between years only for age 1 mean stomach content weight. In the years 2000 and 2001 mean stomach content is greater than in 2002 and 2003 (Kruskal–Wallis $H = 27.4$, $p < 0.01$), but not between each pair of years (Mann–Whitney $U = 7079$, $p = 0.38$ between 2000 and 2001 and $U = 8445$, $p = 0.20$ between 2002 and 2003).

3.4. Decapod crustaceans

Norway lobster is distributed in aggregations in the study area (Sánchez et al., 2002) and is associated with those bottoms that have a sediment suitable to its particular burrowing behaviour. The relative independence of these aggregations and the low mobility of this species have led to the consideration of these aggregations as Functional Units (FU) for management fishery purposes. Three functional units occur in the area covered by this study, West Galicia, North Galicia, and the Cantabrian Sea. To a greater or lesser extent these correspond to sectors MF, FE and PA + AB of the survey sampling design (Fig. 1). Both the landings of the trawl fleet and the indices from surveys (Fig. 10) show a gradual fall over the last decade. The assessment indicates that stock biomass and recruitment are at very low levels (ICES, 2004b) and that urgent management measures must be taken aimed at the recovery of its population. A recovery plan for the Iberian stocks of Norway lobster and hake in the Atlantic Ocean is currently under consideration.

Both the survey immediately after the accident (Sánchez et al., 2003a) and the two autumn surveys of 2003 and 2004 (Fig. 11) showed a strong spatial correlation between the decrease in the abundance of Norway lobster and the area of the greatest impact of the POS in terms of the concentrations of tar aggregates in the sediment (Fig. 2). This is not

Table 1
Hake diet composition by age in weight percentage during 2001, 2002 (pre-spill) and 2003 (post-spill) surveys

Age 0 (<17 cm)	2001	2002	2003
Crustacea	39.88	33.38	41.13
Decapoda	1.95	9.30	17.19
Natantia	1.95	7.56	16.80
Chlorotocus crassicornis	0.00	0.00	9.10
Natantia undet.	0.39	3.83	5.48
Euphausiacea and Mysidacea	37.09	23.73	21.67
Mollusca	0.00	6.97	5.04
Cephalopoda	0.00	6.97	5.04
Decabrachia	0.00	6.97	4.83
Alloteuthis spp.	0.00	6.97	2.10
Fish	60.12	59.65	53.83
Anacanthini	18.48	39.72	15.84
Gadidae	18.48	39.72	11.65
Gadiculus argenteus	18.48	39.72	4.83
Gaidropsarus macrophtalmus	0.00	0.00	3.67
Micromesistius poutassou	0.00	0.00	3.15
Merlucciidae: *Merluccius merluccius*	0.00	0.00	4.20
Callionymoidei and Gobioidei	0.00	0.00	1.89
Percoidei	0.00	0.00	12.80
Carangidae: *Trachurus trachurus*	0.00	0.00	12.80
Fish Undet.	41.63	19.93	23.29
No. stomachs analysed	91	129	386
% Empty stomachs	12.1	46.5	35.0
No. regurgitated stomachs	35	17	62
Mean fullness (g)	0.53	0.51	0.47
Mean length (cm)	12.78	12.82	13.9
Age 1+ (>16 cm)	**2001**	**2002**	**2003**
Crustacea	0.00	0.22	0.58
Mollusca	0.00	0.00	0.26
Fish	100.00	99.78	99.16
Anacanthini	55.06	95.09	80.09
Gadidae	55.06	95.09	77.93
Micromesistius poutassou	53.07	93.36	77.37
Merlucciidae: *Merluccius merluccius*	0.00	0.00	2.16
Isospondyli	0.00	0.00	1.14
Argentinidae: *Argentina sphyraena*	0.00	0.00	1.14
Percoidei	0.00	0.00	12.65
Carangidae: *Trachurus trachurus*	0.00	0.00	9.38
Fish Undet.	44.85	4.69	5.28
No. stomachs analyzed	50	54	205
% Empty stomachs	28.0	40.7	31.7
No. regurgitated stomachs	15	18	42
Mean fullness (g)	24.96	14.94	15.98
Mean length (cm)	26.84	29.24	26.19

Only preys with more than 5% of the total stomach weight are shown.

evident in the abundance indices for the whole of the area (Fig. 10), but it is so if we consider the area of greatest impact separately (Fig. 12), in which mean densities in the post-spill period are significantly lower than those of the pre-spill period (Kruskal–Wallis test: $H = 8.35$, $p = 0.04$). This can be explained only by an increase in the mortality of this species in the most affected area, or by a problem of access of the sampling system caused by changes in its behaviour.

Abundance indices of *Plesionika heterocarpus* decreased noticeably in autumn 2003 compared with preceding years (1999–2002 series), although in 2004 densities recovered and were even higher than those recorded before the spill (Fig. 13). The mean densities in the area of maximum impact showed a pronounced decrease in 2003 followed by a remarkable rebound in 2004 (Fig. 12).

No traces of oil were found in any of the 42 stomachs of Norway lobster or the 616 stomachs of *Plesionika heterocarpus*. No significant correlations were found between amount of oil (g 15 min haul) collected by trawling and stomach fullness for Norway lobster ($r = 0.078$; $p = 0.82$, $n = 5$). In *Plesionika heterocarpus* after combining both surveys, the Spearman coefficient was negative ($r = -0.311$) (i.e. the relationship of least fullness expected in areas where oil density was higher), though non-significant ($p = 0.14$). Stomach fullness was not significantly correlated with any other environmental variables (latitude, longitude, time, depth: Table 4). Nevertheless, fullness was negatively correlated with longitude (i.e. greater fullness to the east), and positively with time (lower fullness in the morning) with p in both cases close to the chosen level of significance ($p = 0.07$ and $p = 0.08$ respectively). Fullness was higher in hauls in which oil did not occur (0.0046 ± 0.0014 C.I. 95%) than in the five hauls were oil density was the highest (>50 g 15 min haul: 0.0023 ± 0.0014 C.I. 95%), though, once more, differences were not significant.

Calcified decapod crustaceans (Paguridea, Brachyura) were the main prey item found in the diet of Norway lobster both in the oiled and non-oiled areas. Percentages of Paguridea were higher in non-oiled (75.9%) than in oiled (26.8%) areas. Though some changes in the diet may be related to a decrease of detritus feeders (e.g. polychaetes, Paguridea) in oiled areas, the low number of specimens available and analysed placed a serious limitation on the analysis of Norway lobster diet (Table 5).

Polychaetes, euphausiids, Natantian decapods, fish remains and unidentified detritus were the dominant prey items for *Plesionika heterocarpus* (Table 5). Polychetes, euphausiids, and fish remains were more important in the diet in the oiled area, whereas Natantian decapods, and especially unidentified detritus were more important in the non-oiled areas. These differences, however, did not point to any clear trend of benthic or pelagic resources depending on the occurrence of oil on the bottom. Thus, for instance, pelagic prey were consumed both in the oiled areas (e.g. euphausiids) and in the non-oiled areas (e.g. natantian decapods), while detritus and polychaetes (more linked to the benthic compartment) were dominant in the diet in both areas. Detritus was not attributable to a phytodetritic origin as occurs, for example, in bathyal mysids (Cartes and Sorbe, 1998). Only scarce phytoplankton cells were identified after the analysis of detritus under a microscope (×100–×400).

4. Discussion

Values of hydrocarbons in the water column over the continental shelf were found to be lower than expected

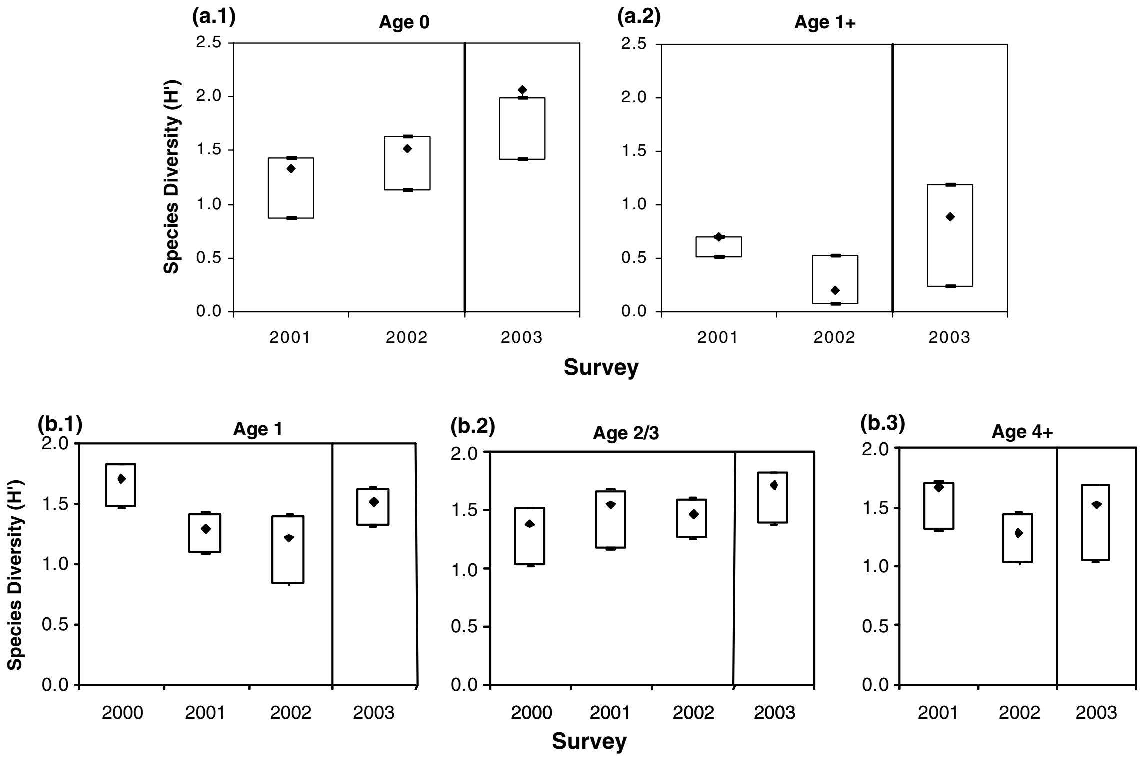

Fig. 6. Mean species diversity (H') in the diet of hake (a.1 and a.2) and four-spot megrim (b.1–b.3) in pre-spill (2000–2002) and post-spill (2003) surveys for each age class. 90% confidence intervals estimated through the percentiles (.05 and .95) of the bootstrap sample distributions.

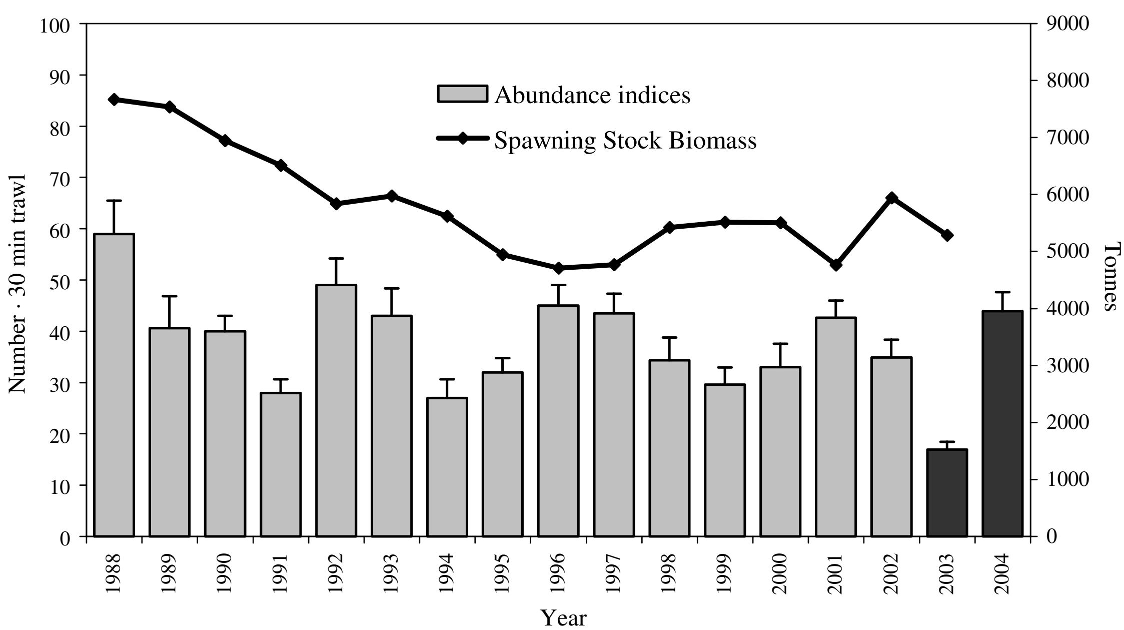

Fig. 7. Historical series (1988–2004) of stratified mean densities of four-spot megrim (number · 30 min trawl ± SE) from surveys and spawning biomass (SSB) of southern stock (tonnes) from ICES 2004.

during the intense phase of the POS given the magnitude of the spill (González et al., 2003). This was probably due to the physico-chemical characteristics of the heavy oil (M-100) spilt and it might also explain the lack of detection of clear effects on planktonic communities (Valdés et al., 2003), which are normally good indicators of hydrocarbon impacts. This implies that the key species were not acutely affected by the PAHs through the gills. We thus consider it more appropriate to monitor the cumulative effects in the medium and long-term through the trophic web, with the emphasis on suspension feeders and detritivorous organisms of the bottom communities.

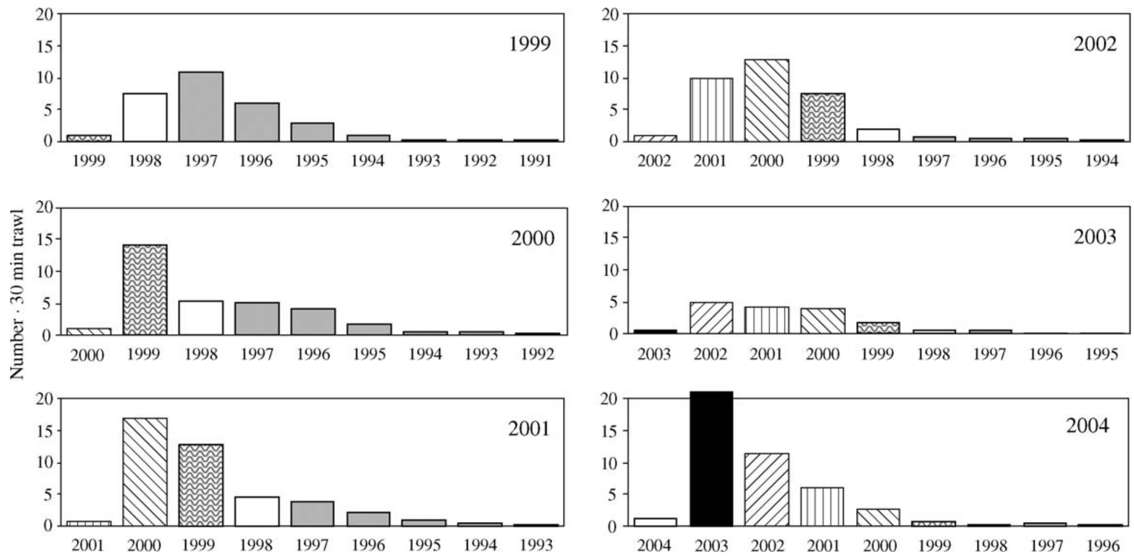

Fig. 8. Year-class distribution of four-spot megrim (number · 30 min trawl) from 1999–2004 bottom trawl surveys. Each cohort has the same shading in its corresponding bars.

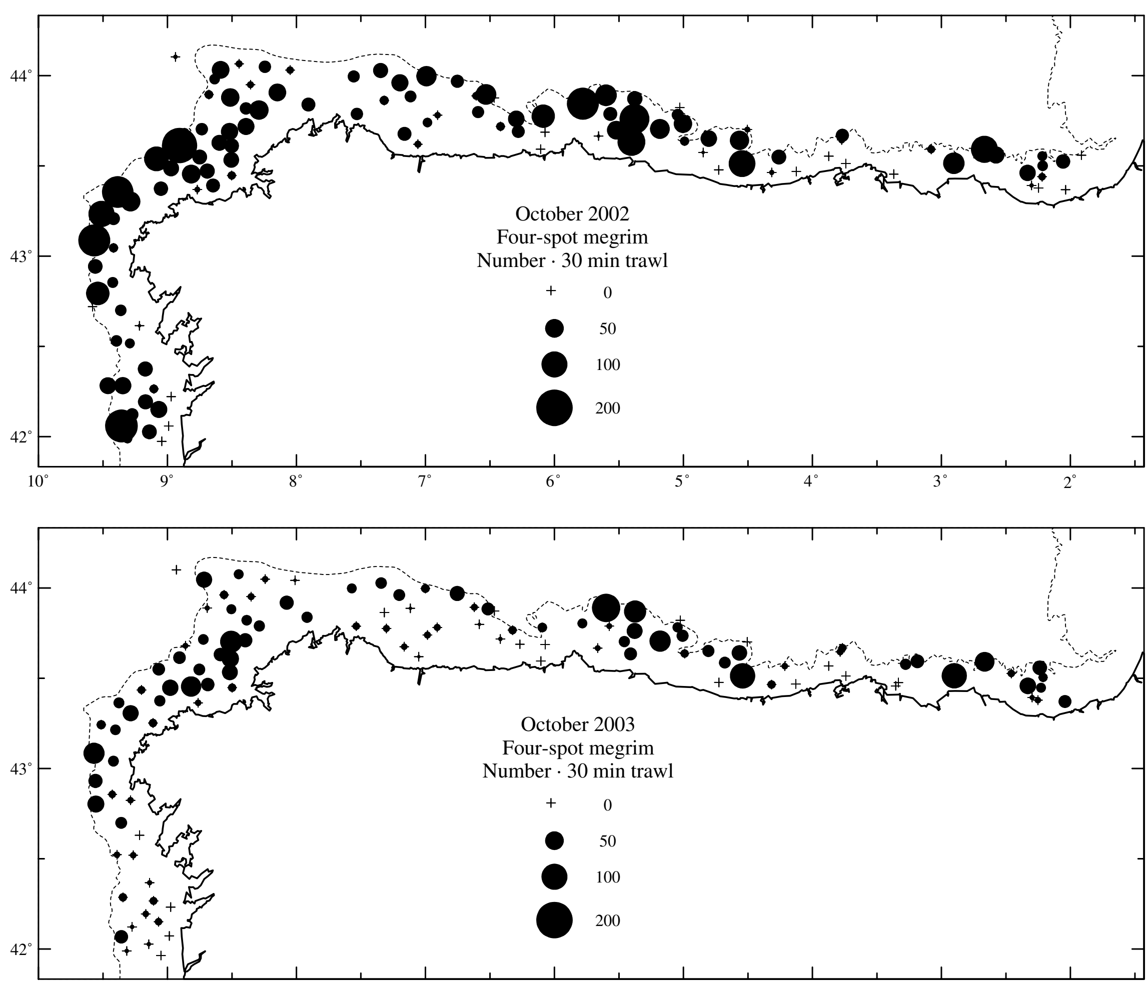

Fig. 9. Four-spot megrim density distribution (number · 30 min trawl) from surveys before and after the *Prestige* oil spill (2002–2003).

Table 2
Four-spot megrim diet composition by age group in weight percentage during 2000–2002 (pre-spill) and 2003 (post-spill) surveys

Age 1 (10–17 cm)	2000	2001	2002	2003
Crustacea	95.66	95.24	83.90	92.06
Decapoda	59.36	72.97	71.24	47.77
Brachyura	15.18	10.66	5.59	5.60
Goneplax rhomboides	7.78	6.79	5.59	4.07
Liocarcinus spp.	7.04	1.89	0.00	1.53
Natantia	44.17	60.64	65.60	41.34
Alpheus glaber	1.67	0.00	1.72	9.30
Chlorotocus crassicornis	6.99	0.00	0.00	0.83
Crangonidae undet.	5.24	14.93	14.44	5.28
Pandalina brevirostris	0.00	6.11	0.00	1.11
Processa spp.	27.26	34.64	43.28	16.69
Natantia undet.	3.01	4.97	6.16	4.80
Euphausiacea and Mysidacea	26.56	19.82	12.21	40.98
Crustacea Undet.	6.62	2.38	0.02	1.33
Fish	4.26	4.76	16.10	6.94
Anacanthini	1.47	0.00	10.75	0.00
Gadidae: *Gadiculus argenteus*	1.47	0.00	10.75	0.00
Callionymoidei and Gobioidei	1.10	0.00	3.01	3.49
Fish Undet.	1.69	4.76	2.34	3.46
Annelida: Polychaeta	0.07	0.00	0.00	0.60
No. stomachs analyzed	120	126	110	168
% Empty stomachs	18.33	15.87	25.45	19.05
Mean fullness (g)	0.26	0.26	0.21	0.21
Mean length (cm)	15.2	15.3	15.4	15.0
Age 2/3 (18–24 cm)	**2000**	**2001**	**2002**	**2003**
Crustacea	74.45	67.62	72.01	74.75
Decapoda	69.41	63.65	67.98	65.48
Brachyura	18.11	14.63	9.16	15.18
Goneplax rhomboides	10.45	13.95	9.06	13.66
Liocarcinus spp.	7.67	0.59	0.00	1.46
Natantia	51.30	47.59	55.91	49.67
Alpheus glaber	8.95	4.42	9.68	8.70
Chlorotocus crassicornis	5.99	0.93	4.96	0.40
Crangonidae Undet.	12.61	4.20	2.15	3.29
Processa spp.	12.20	12.51	12.26	14.59
Solenocera membranacea	0.00	7.45	11.80	11.73
Natantia Undet.	11.54	16.91	12.70	9.95
Euphausiacea and Mysidacea	3.70	3.28	2.75	8.14
Mollusca: Cephalopoda	0.00	0.11	1.19	0.42
Fish	25.50	32.27	26.70	24.01
Anacanthini	8.65	14.15	19.83	9.77
Gadidae	8.65	14.15	19.83	9.77
Gadiculus argenteus	8.65	5.62	19.83	6.97
Gaidropsarus macrophtalmus	0.00	8.53	0.00	2.8
Callionymoidei and Gobioidei	0.00	3.47	3.42	4.74
Fish Undet.	16.86	14.65	3.45	6.44
Annelida: polychaeta	0.04	0.00	0.09	0.82
No. stomachs analysed	66	171	187	311
% Empty stomachs	27.27	28.07	33.16	20.26
Mean fullness (g)	0.67	0.81	0.79	0.54
Mean length (cm)	20.94	20.80	21.21	20.94

Only main groups and preys with more than 5% of the total stomach weight are shown.

Measurements of PAHs in sediments of the continental shelf made a few months after the catastrophe showed a spatial distribution that seemed more closely related with a chronic impact of harbour activities than the effects of the POS (Soriano et al., 2003). Nevertheless, abundant POS hydrocarbons in the form of tar aggregates across large areas of the continental shelf suggest that there must have been hydrocarbons from the surface in the water column, either in aggregates of low bioavailability or in the form of small toxic particles in the sea snow. This dangerous component of the sea snow must have consisted of oil degradation products and dead or agglutinate planktonic organisms, although this has been impossible to quantify as specific surveys to these effects were not conducted. This hypothesis of oil being carried to the bottom of the continental shelf by means of sea-snow is supported by the fact that planktonic organisms (copepods) with oil on the exoskeleton and inside the body were found in waters off La Coruña in November 2002 (Bode et al., 2003). Furthermore, during sampling of supra-benthic communities using a sledge with a 0.5 mm mesh (Serrano et al., 2005, this volume), we found small oil drops in individual amphipods and in the sampling nets (Frutos and Parra, 2004).

Owing to their diffused characteristics, the effects of the POS on fish species may well be mainly sublethal, affecting health, growth or reproduction in the medium or long-term. The experience of the *Exxon Valdez* oil spill (EVOS) shows that unexpected persistence of toxic subsurface oil and chronic exposures, even at sublethal levels, have continued to affect wildlife and postponed their recovery (Peterson et al., 2003). It is characteristic of the area affected by the POS that a high percentage of the primary production is exported to the bottom as particulate organic matter (OSPAR, 2000); consequently, detritivorous species are an indicative component of the ecosystem with respect to oil impacts. Muddy bottoms are very common in the Galician and Cantabrian Sea shelves and support a high biomass of fish species and benthic communities (Sánchez and Serrano, 2003).

The most critical POS event coincided with the end of the annual gonadal development of hake and four-spot megrim (Pérez and Pereiro, 1985), but there was a considerable presence of large masses of oil floating on continental shelf waters during spawning (January–March) and larval and post-larval development (February–April). Important effects of the *Exxon Valdez* oil spill on the eggs and larvae of Pacific herring (Brown et al., 1996) and pink salmon have been described (Geiger et al., 1996), but these species spawn and reproduce in nearshore habitats where the residual oil in the gravel increased embryo mortality (Bue et al., 1998; Carls et al., 2002). Exposure and possible adverse effects of the EVOS at depth were examined in several species of demersal and benthic crustaceans, molluscs, and finfish (Armstrong et al., 1995). It appears that long-term trends in abundance of populations of these species due to natural environmental causes or fishing pressure are likely to be far more important than fluctuations attributable to EVOS, but deep water demersal fishes do show biochemical indicators of induction of the detoxification processes after exposure to the oil (Peterson, 2001).

Table 3
Four-spot megrim age 4+ diet composition in weight percentage during 2001–2002 (pre-spill) and 2003 (post-spill) surveys

Age 4+ (⩾24 cm)	2001	2002	2003
Crustacea	66.04	39.36	67.35
Decapoda	62.97	37.26	66.29
Anomura: *Munida* spp.	12.44	0.93	1.74
Brachyura	21.53	4.62	8.71
Goneplax rhomboides	14.56	4.58	8.16
Liocarcinus spp.	6.97	0.03	0.55
Natantia	29.00	31.71	55.71
Alpheus glaber	4.51	1.96	5.41
Plesionika heterocarpus	0.00	14.56	0.42
Processa spp.	2.11	6.59	5.09
Solenocera membranacea	17.25	0.86	35.00
Natantia undet.	5.14	6.42	6.51
Mollusca: Cephalopoda	0.00	0.00	1.30
Fish	33.96	60.64	30.79
Anacanthini: Gadidae	13.27	51.57	12.88
Gadiculus argenteus	0.00	31.14	7.55
Gaidropsarus macrophtalmus	13.27	19.57	5.34
Callionymoidei and Gobioidei	0.00	0.95	3.09
Fish Undet.	20.70	6.83	12.53
No. stomachs analysed	51	76	123
% Empty stomachs	39.2	40.8	28.5
Mean fullness (g)	1.80	2.38	1.38
Mean length (cm)	27.39	27.36	26.69

Only main groups and preys with more than 5% of the total stomach weight are shown.

4.1. Hake

Hake spawns in the study area from December to April, when adults concentrate at certain sites in the shelf break area (Pérez and Pereiro, 1985). The existence of successive partial spawns has been described (Murua et al., 1996) and any potential effects of the POS on hake spawning should be interpreted in this context. Hake larvae remain resident in the plankton until they metamorphose to the juvenile stage, which takes about 2 months in depths of between 50 and 150 m (Motos et al., 1998). Therefore, the drift of eggs and larvae from spawning sites to the nursery areas has been associated with the particular current regime during the winter and spring (Sánchez et al., 2001). Sánchez and Gil (2000) describe the importance of the *Navidad* (Christmas) current in the success or failure of annual hake recruitment. This well-known winter warm flow, in combination with spring upwelling events, defines an optimal environmental window (OEW) by controlling the drift of larvae to either the nursery areas or off-shelf oceanic waters (Sánchez et al., 2003b). The tragic concurrence of the POS with the 2002/2003 *Navidad*-poleward-flow (García-Soto, 2004), in combination with local winds, has made the *Prestige* accident one of the most extensive oil spills in history. The same current that carried the oil slicks away from the shelf of the sector EP (Estaca-Peñas), a fact corroborated by the Lagrangian bouys tracked by satellite (www.cmima.csic.es/prestige) and by the almost null impact of the black tides on the western coast of the Cantabrian Sea, may have been responsible for the weakening of the historical hake nursery in this area in 2003. In this way, a spatial distribution pattern of recruits (Fig. 5b) appeared that was similar to that of the tar aggregates (Fig. 3) over the Cantabrian Sea continental shelf. The POS and the hake larvae were fellow travellers in different water column layers during the winter and spring of 2003.

Concentrations of PAHs in the water column were not as high as expected (González et al., 2003), but a percentage of hake larvae must have been subjected in some way, directly or indirectly (their preys), to the effects of the POS through the water column. At the time of writing

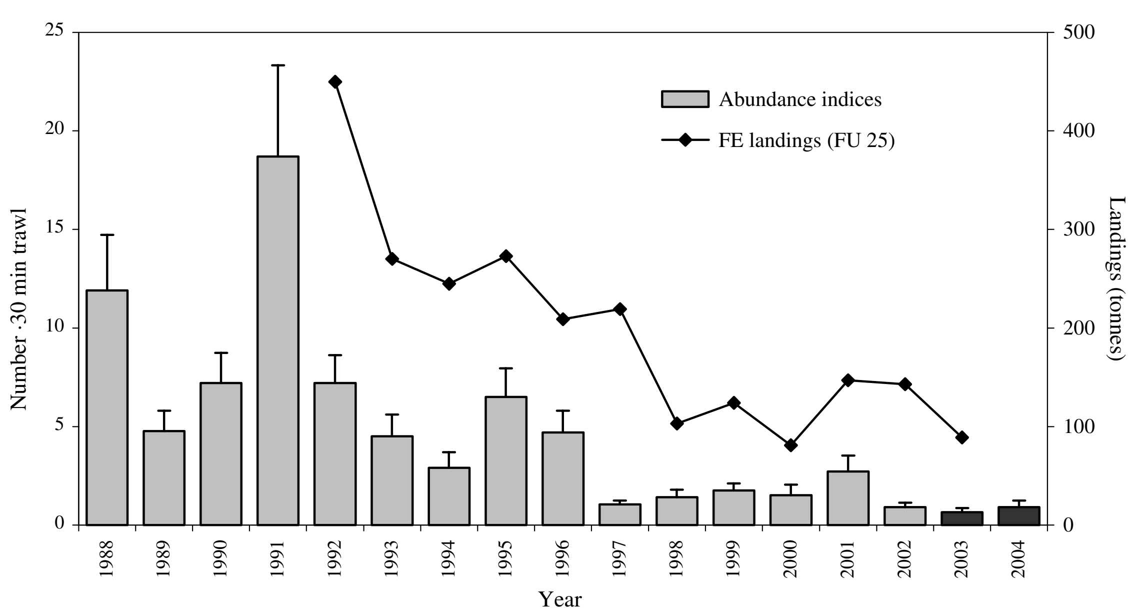

Fig. 10. Historical series (1988–2004) of stratified mean densities of Norway lobster (number · 30 min trawl ± SE) in the total area and landings (tonnes) from FE sector (Functional Unit 25).

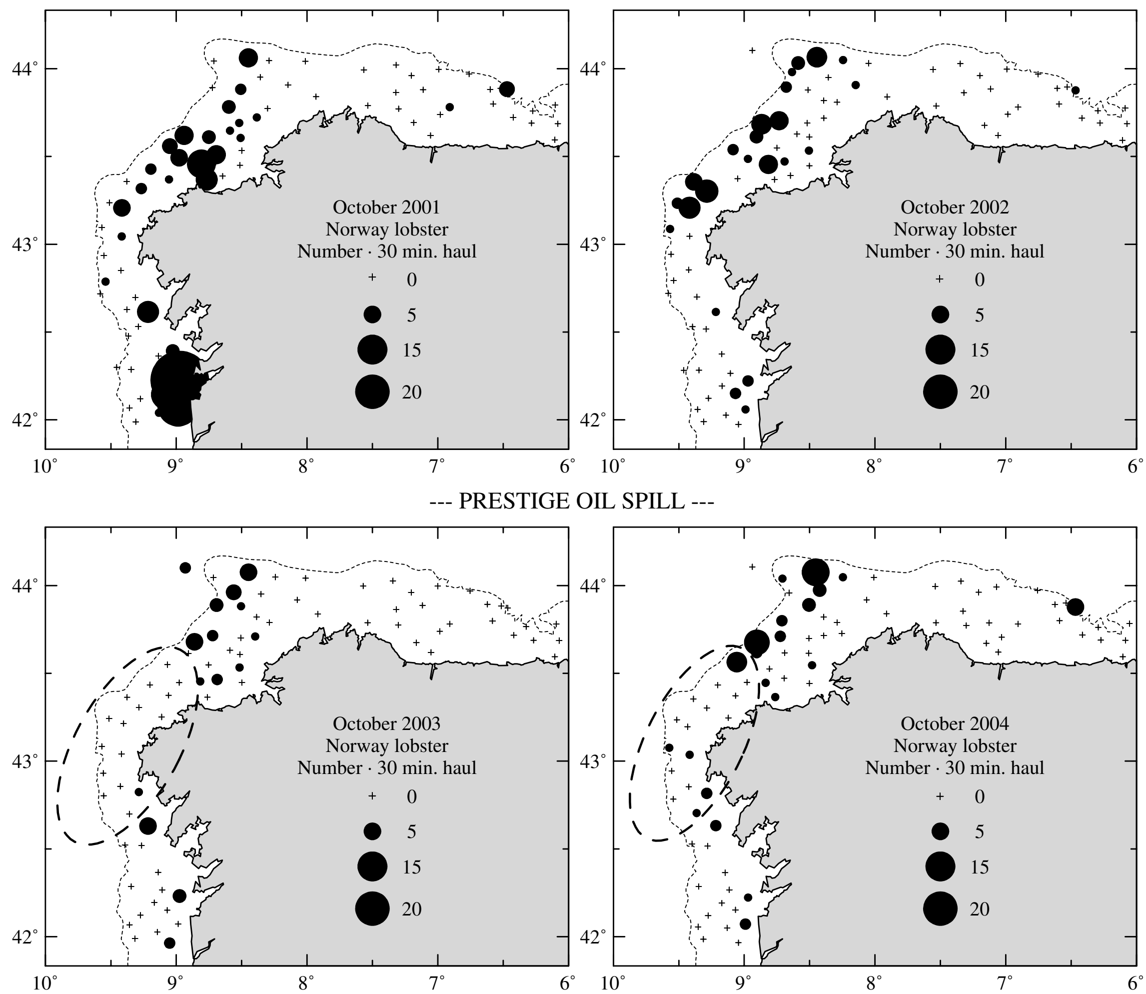

Fig. 11. Norway lobster distribution (number · 30 min trawl) from surveys before and after the *Prestige* oil spill (2001–2004).

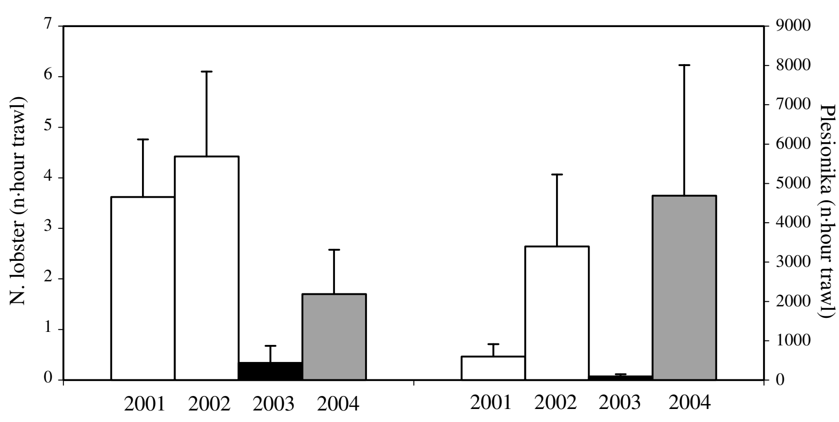

Fig. 12. Mean densities of Norway lobster and *Plesionika heterocarpus* (number · hour trawl ± SE) in the zone of maximum impact (2001–2004).

we have not found any effects on the population of this species, but the studies in progress in relation to sublethal effects on the growth or spawning potential of this species may, perhaps, provide us with important insights. The inhibition of gonadal development in juvenile fish through induction of greater loads of parasites in some of the demersal fishes after chronic exposure to *Exxon Valdez* oil inevitably led to an increase in maturity age, and hence, to a reduction in the spawning stock biomass, as was shown by Khan (1990). Hake had already shown very high levels of parasitic infection by *Anisakis* in recent years, reaching 98% in the area of Galicia (Mattiucci et al., 2004). Hake population was already outside safe biological limits due to overfishing before the catastrophe of the

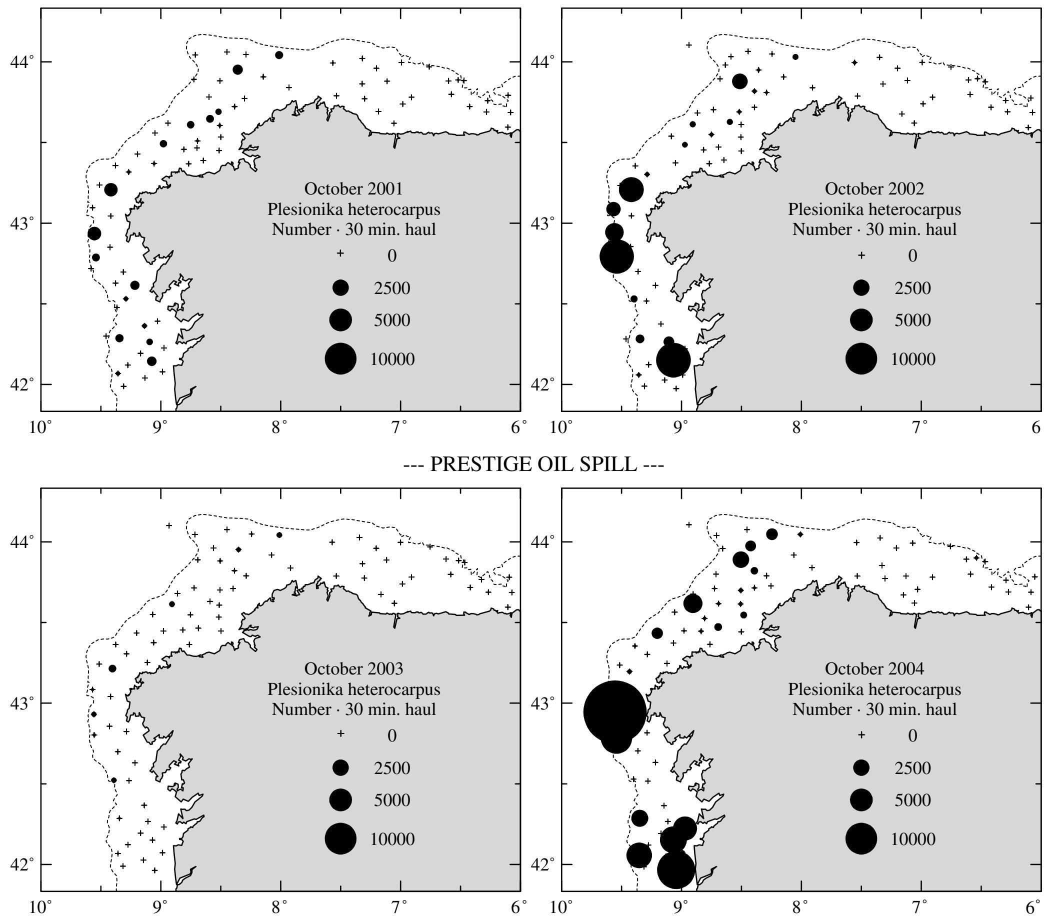

Fig. 13. Pandalid shrimp (*Plesionika heterocarpus*) distribution (number · 30 min trawl) from surveys before and after the *Prestige* oil spill (2001–2004).

Table 4
Spearman rank order correlation between fullness by *Plesionika heterocarpus* and some haul variables

	n	*r*	*p*-level
f vs. latitude	24	0.262	0.226
f vs. longitude	24	−0.381	0.066
f vs. depth (m)	24	−0.047	0.827
f vs. oil (tar aggr.)	24	−0.311	0.139
f vs. time	17	0.436	0.080

n: Number of individuals.

Prestige (ICES, 2004a). This unstable situation might worsen and lead to a collapse of the stock if the possible sublethal effects caused by the POS affect the health of its population.

4.2. Four-spot megrim

The survey series used in this work has a strong weight in the XSA model applied in the assessment of the southern stock of this species (ICES Divisions VIIIc and IXa), providing good estimates for young and middle ages (ICES, 2004a) and covering the entire distribution area of the species. Our results show that the weak cohort of 2001 does not fully explain the large decline in the abundance indices of four-spot megrim in the year following the POS, since practically all the age–classes were affected by a considerable reduction. According to the estimates of the latest assessment available (ICES, 2004a), the spawning stock biomass (SSB) decreased between 1978 and 1996 and before remaining relatively stable at a low level (∼5000 tonnes). The SSB of 2002 showed a slight recovery (Fig. 7), which should correspond to a predictably good cohort for 2003 and the results of the survey on the year class indicated that this was so (Fig. 8). The surprising recovery of the abundance indices of the 2001 and 2002 age–classes obtained during the 2004 survey may invalidate the hypothesis of an increase in mortality due to the POS. As a consequence, the most likely explanation of what happened to four-spot megrim in 2003 is a problem of gear accessibility. This is also corroborated by the low CPUEs of the trawl fleet (ICES, 2004a) during the same period as the survey (fourth quarter of 2003).

The Working Group on this stock (ICES, 2004a) estimates a slight increase in fishing mortality in 2003 (0.23 against 0.17 in 2002) and consequently an increase in the landings of this species. Nevertheless, the POS prompted a redistribution of fishing effort, particularly in the Galician area. Some regulatory measures, such as spatial and seasonal closures, were adopted to minimize the impact

Table 5
Diet of Norway lobster and *Plesionika heterocarpus* based on the spring survey of 2003 in oiled and non-oiled hauls

Diet wet weight (g)	Norway lobster		*P. heterocarpus*	
	Oiled	Non-oiled	Oiled	Non-oiled
	$n = 11$	$n = 10$	$n = 44$	$n = 53$
Hydrozoa	0	0	0	0.005
Polychaeta unident.	0.019	0.552	0.035	0.021
Glycera spp.	0	0	0	0.013
Aphroditimorfa	0	0	0.063	0.011
Crustacea unident.	0.028	0	0.044	0.069
Copepoda Calanoida	0	0	0.004	0
Amphipoda Gammaridea	0	0	0.014	0
Lysianassidae	0	0	0.007	0
Ampelisca sp.	0	0	0.007	0
Amphipoda Hyperiidea	0	0	0.027	0.005
Natatolana borealis	0	0	0	0.117
Mysidacea	0	0	0.011	0.003
Euphausiacea	0	0.002	0.067	0.054
Decapoda Natantia	0	0.092	0.042	0.061
Decapoda Reptantia	0.044	0.737	0	0
Brachyura	0.176	0	0.002	0
Paguridea	0.347	6.102	0	0
Nephrops norvegicus	0.549	0	0	0
Gastropoda	0.014	0.004	0.045	0.013
Bivalvia Taxodonta	0.044	0	*	0.006
Ophiuroidea	0.003	0	0	0.027
Osteychthyes remains	0.031	*	0.063	0.055
Eggs of Belonidae	0	0	0.023	0
Gelatinous remains	0	0	0.078	0
Unidentified	0.016	0	0.002	0.036
Detritus	0	0	0.040	0.132
Carbon	0.003	0.003	0.002	0.013

n: Number of individuals analyzed; (*) weight < 0.001 mg.

of the oil on catches (Punzón et al., 2005). The main trawl fleets that work in the affected area show a fall of 15% in their activity in 2003, and a less dramatic decrease in catches is also reported for the A Coruña trawl fleet (ICES, 2004a). Nevertheless, it must be borne in mind that the closure due to the POS might have had a favourable impact by reducing fishing mortality in part of the year. Moreover, the aforementioned 2003 increase in fishing mortality estimated in the last assessment has to be treated with caution, since some of the assumptions of the assessment model used for four-spot megrim (e.g. constant natural mortality and catchability) are clearly invalidated by a catastrophe such as the POS, besides which the stock assessed inhabits the whole Atlantic Iberian peninsula including the eastern Cantabrian shelf and the Portuguese area, not just the most affected area of the Galician coast.

Chronic exposures for years following the EVOS, which persisted in sedimentary refuges, were evident from biomarkers in fish closely associated with sediments for egg laying or foraging, and enhanced mortality for years (Jewett et al., 2002). The study carried out on the response of a battery of biomarkers in individuals of four-spot megrim caught during April 2003 shows significant positive correlations between antioxidant enzymes (glutathione reductase and catalase) and the concentrations of tar aggregates at different areas of the north Iberian shelf, pointing to the *Prestige* oil spill as the cause of the impact (Martínez-Gómez et al., 2005, this volume).

4.3. Decapod crustaceans

Some of the observed changes in the density of decapod crustaceans off Galicia before and after the POS suggest some negative effects of the spill on population densities. Nevertheless, (1) similar fluctuations were observed on a local scale prior to the spill, from autumn 1999 to autumn 2002 in the case of Norway lobster; (2) two years after the spill and one year after the low abundances found in 2003, populations of *Plesionika heterocarpus* recovered and even showed higher densities than those recorded before the spill, and (3) from a feeding point of view, oil was not ingested, at least as macroscopic particles (observed ×40), by decapod crustaceans in our study. After the *Exxon Valdez* oil spill, no significant differences in the CPUE of the Pandalid shrimp *Pandalus borealis* were detected between oiled and non-oiled sites (Armstrong et al., 1995).

4.4. Feeding implications

Oil spills affect fish and megafaunal invertebrate feeding in different ways. For example, stomach fullness indices increased for juvenile *Gadus morhua* one year after the Exxon Valdez oil spill in oiled sites (Peterson, 2001). This increment in consumption was directed at small invertebrates (mainly molluscs) and it has been hypothesized that these prey increased due to the removal of their natural predators. Among crustaceans, some negative effects by oil spills were observed in the feeding behaviour of *Homarus gammarus*, with some specimens rejecting food when exposed to threshold oil concentrations in tanks (Laurenson and Wishart, 1996). In any case, either of the two effects (lower stomach fullness with higher oil concentration, or higher stomach fullness after the spill linked to changes in diet composition) were not statistically demonstrated in our target species. Neither hake nor four-spot megrim showed noteworthy differences in stomach fullness or emptiness percentage after the POS, and the figures found in 2003 are within the variability in surveys carried out before the POS, since statistically significant differences do not point to 2003 as being distinct concerning these predators' diets. Similarly, no significant differences in food consumption were found in pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) after the *Exxon Valdez* oil spill by Sturdevant et al. (1996). Also, Carls et al. (1996) found that the pink salmon feeding rate decreased only when food was highly contaminated with crude oil, but not with low concentrations.

Plesionika heterocarpus showed higher (though not significant) fullness in non-oiled hauls than in oiled areas. There was also a negative (though again not significant) correlation between fullness and the amount of oil on the seabed, though fullness in this case also seemed to depend on environmental variables (time of day and duration of hauls). The lowest values of fullness obtained in oiled hauls off Galicia (0.0023) for *P. heterocarpus* were below the range obtained in the Alboran Sea (0.0026–0.0137) by Fanelli and Cartes (2004) in daylight in a spring survey. Differences may be attributable to interannual variations or related to the high local productivity of the Alboran Sea, an upwelling area. The occurrence of oil on the seabed did not change the composition of the diet of our two target species, and changes detected were related to haul variables (time of day and geographical location in the case of *P. heterocarpus*).

Diet composition for hake and four-spot megrim did not present outstanding differences that can be related to the POS when compared with previous surveys. Annual variability was taken into account by comparing the differences between the years before the POS, as in the case of silvery pout (*Gadiculus argenteus*), which decreased its contribution to the diets of both fish predators studied in 2003 compared with 2002, but only to levels already recorded in previous years. Besides, most of the differences found present different signals in different age groups or species, e.g. supra-benthic and pelagic crustaceans (mysids and euphausiids) increase their importance in the diet of younger ages of four-spot megrim but slightly decrease for hake age 0, just the opposite trend to that found in decapod crustaceans, which increase their importance in younger megrim diet but increase in that of hake.

The predator diets in 2003, and those of previous years, are also in agreement with previous descriptions of the diet of these species (Olaso and Rodríguez-Marín, 1995; Velasco et al., 1996; Velasco and Olaso, 1998; Preciado et al., 2002). In the same way, results observed in the diet of Norway lobster and *Plesionika heterocarpus* in affected fishing grounds off Galicia agree, in general, with previous data reported for these species in other neighbouring bottoms (unaffected by oil spills), the case of Norway lobster in the Bay of Biscay (Lagardère, 1977), and in the Bay of Cadiz (Cristo, 1998; Cristo and Cartes, 1998). There, decapods, euphausiids, peracarid crustaceans and fish were the major prey observed in the diet of Norway lobster. Diets similar to those reported here for *Plesionika heterocarpus* were also found in other (unaffected) areas. Thus, in the Bay of Biscay, shrimp mainly consumed polychaetes (Lagardère, 1977), while in the Alboran Sea (Fanelli and Cartes, 2004) the main prey were more pelagic (euphausiids) and suprabenthic (mysids).

In spite of not finding any apparent effects on diet and feeding intensity in our study, there may have been some negative effects via feeding. The growth rate is reported to have been reduced by ingestion of oil-contaminated food in pink salmon even with no reduction in food consumption when oil concentrations were low (Carls et al., 1996). A reduction was also found in Atlantic salmon (*Salmo salar*) and explained by a reduction in food conversion efficiency rather than by changes in food intake (Vignier et al., 1992). Another explanation of this decrease in growth rate is that energy is expended to metabolise the hydrocarbons at the cost of somatic growth (Willete, 1996). These reduced growth rates result in a greater exposure to predation and a lower ability to feed, in addition to delaying reproduction. Regarding crustaceans, suspension feeding on small particulate organic matter and organisms (nauplii and *Artemia salina*) has been documented in adult decapods such as crabs, anomurans, and in Norway lobster itself (Selborn, 1996), though possible oil remnants the size of nauplii might be observed in our case under ×40. Dissolved compounds of oil may also have negative effects on decapods and other large megabenthic marine organisms. In the case of oil spilled by the *Prestige*, however, this heavy oil showed high chemical stability.

A high coverage of oil on bottoms may have negative effects on territorial species such as the Norway lobster. Nevertheless, the *Prestige* oil detected here occurred in infralitoral waters (50–500 m) and lay on soft bottoms in isolated masses with low coverage and lower concentration in sediments. With the exception of some closed bays (the case of the Amoco Cadiz), the documented biological effects of oil in the subtidal (and by extension also probably in the infralitoral) regions are generally of short duration and a recovery to equilibrium or 'normal' conditions is typically quite rapid (Lee and Page, 1997).

The information presented here was distilled from several studies of a multidisciplinary project which is still in progress at the time of writing. Monitoring continues given that the possible consequences of the POS may appear in the longer term and more information is required in order to understand them in all their dimensions and inter-relationships. A considerable effort is being made in the study of biomarkers, reproductive potential and growth in a number of key species of the continental shelf. To help synthesize all this information, a mass balance model of trophic interactions (Ecopath, with dynamic routines Ecosim and Ecospace) will be constructed to summarise available ecosystem information and understand the dynamic of changes associated with the POS.

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