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Influence of environmental factors on commercial trawl catches of *Nephrops norvegicus* (L.)

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Environmental factors that affect small-scale spatio-temporal variability in commercial catch rates of *Nephrops norvegicus* are analysed. Catch and effort data were obtained from a selection of fishers that operated in the *Nephrops* fishery on a daily basis, and the environmental factors studied were those considered by the fishers themselves to be the ones driving variability in the fishery. Using multivariate regression analysis and MANOVA, depth, atmospheric pressure, cloud cover, and sea state were found to affect the catch rate of the *Nephrops* deep-water fishery in the northwestern Mediterranean. The results are consistent with the hypothesis already in the scientific literature that the light intensity reaching the seabed has a primary influence on the activity rates of *Nephrops* and hence the species' vulnerability to trawling. The value of collaborating with fishers in establishing scientific hypotheses and obtaining data, and specifically drawing on their knowledge of the ecosystem in which they operate, is shown by this study, a case study in integrating Traditional Ecological Knowledge (TEK) into fisheries management.

Keywords: catchability, commercial trawlers, environmental factors, Mediterranean Sea, *Nephrops norvegicus*, Traditional Ecological Knowledge.

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Introduction

The catchability of exploited populations is a key parameter in fish stock assessment, relating catch per unit effort (cpue) of a given stock to total population size (Caddy, 1979; Arreguín-Sánchez, 1996). Quantifying it is essential in obtaining precise population indices in fisheries ecology and, although it is often assumed to be constant, studies in several fish species have revealed that environmental factors play a role in its variability (Dorel *et al.*, 1985; Ehrich and Groger, 1989; Orsi-Relini *et al.*, 1997; Perry *et al.*, 2000). Following the scheme proposed by Laurec and Le Guen (1981), catchability can be partitioned into three components: geographical accessibility of the fishing grounds, vulnerability of the species to the fishing gear, and efficiency of the fishing gear. In this study, we analyse the environmental factors that may affect the vulnerability component of the catchability of Norway lobster (*Nephrops norvegicus*) to trawl gear, as a basis for understanding variations in cpue observed in the fishery. *Nephrops* is a commercially important species off the Catalan coast (NW Mediterranean Sea) and elsewhere in European waters (Sardà, 1998; ICES, 1999). Its biology is well known, and two recent reviews by Sardà (1995, 1998), for Atlantic and Mediterranean populations, are a source of information on its biology and ecology.

Variations in landings and catch rate of *Nephrops* at a seasonal scale are well known, the yield being greater in spring and summer and lower in autumn and winter, in both the Mediterranean and the Atlantic (Farmer, 1975; Sardà, 1998). Along with seasonal variation, sudden variations in cpue are common, at short time scales (typically within a week). Local fishers attribute such variations to changes in the vulnerability of the resource cued by environmental factors, such as cloud cover, water currents, and changes in the weather, and even to small-scale seismic movements. Studies in the Irish Sea confirm that light intensity and near-bottom turbidity also influence small-scale variations in catchability of *Nephrops* (Hillis, 1996).

As with other Mediterranean fisheries, the *Nephrops* fishery is not monitored routinely at small spatio-temporal scales, and monthly official statistics per port are often incomplete or inaccurate. Owing to the lack of appropriate time-series on catch and environmental variables, little is known of the space-time dynamics of *Nephrops* at regional scales in the Mediterranean Sea. Space-time variations in cpue are an important aspect of a fisheries system, and they need to be incorporated in assessment protocols. The lack of routine monitoring of the *Nephrops* fishery in the northwestern Mediterranean prompted us to initiate exploratory collaboration with fishers in an attempt to improve management. For the purpose, we enlisted the cooperation of fishers active in the *Nephrops* fishery in the study area, and we gave notice that we were receptive to their beliefs on which environmental factors could explain the patterns of variation in *Nephrops* cpue. Fishers have the advantage over scientific monitoring schemes in that they observe fisheries ecosystems on a daily basis, so their scale of observation is better than that of a traditional scientific survey.

It is important to integrate the knowledge of fishers in fisheries management (Mackinson and Nøttestad, 1998; Freire and García-Allut, 1999). However, data furnished by them must be processed and filtered appropriately to make them usable for purposes of scientific advice (Sardà and Maynou, 1998; Perry *et al.*, 2000).

The primary aim of this paper was to identify the environmental conditions affecting the vulnerability of *Nephrops* to trawl gear. However, there was an additional and more general objective to ascertain whether environmental observations made by fishers with in-depth knowledge of a particular fishery (in this case, the *Nephrops* fishery off the Catalan coast) can be used scientifically to enhance knowledge of a fisheries ecosystem. Ultimately, we wanted to know whether the information we collected from fishers could contribute meaningfully to assessment and management of the stock.

Material and methods

Data sources

Nephrops landings in Catalonia amount to ca. 200 tons yr^{-1}, with a current value of 3.5 million Euro and an average price at first sale ashore of ca. 30 Euro kg^{-1}, making it a target species for the trawl fleet. In the Mediterranean, the species is caught by a semi-industrial trawl fleet (engine power 500–1500 hp) that operates by making daily trips to the fishing grounds located 10–40 miles offshore. The fleet of each port works exclusively on its nearest fishing ground, resulting in there being almost no spatial overlap of fishing effort between contiguous ports. The yield of the fishery varies considerably at small spatio-temporal scales, e.g. within weeks and within fishing grounds.

We conducted a survey among selected fishers at specific ports to obtain day-to-day data on environmental conditions and cpue. The survey consisted of distributing logbooks specifically designed for the purpose of this study among reliable fishermen for a period of some two years. The ports selected were Barcelona, Vilanova i la Geltrú, Tarragona, L'Ametlla de Mar and Sant Carles de la Ràpita (Figure 1), which together account for 94% of the landings of *Nephrops* in the study area (central and southern Catalonia). The fishers selected targeted *Nephrops* on a regular basis, operating five boats (one at each port) of similar technical characteristics (700–900 hp, 50–80 GRT, 17–24 m, the same type of trawl). For each fishing operation targeting *Nephrops*, fishers were required to report, on a haul-by-haul basis, the environmental and technical conditions of their fishing activity. The fishers selected were on personal terms of confidence with the researchers involved, so guaranteeing the reliability of the data provided.

Several fishers expressed the belief that sudden variations in *Nephrops* catchability could be attributable to low-intensity seismic movements. Considering that *Nephrops* inhabit fluid, muddy substrata, we took this theory as a working hypothesis and obtained the data series on seismic movements for the Catalan area from the Geological Service of the Autonomous Government of Catalonia for 1993–1995 (Generalitat de Catalunya, 1993–1995).

The environmental variables reported by fishers are listed in Table 1. Note that some variables were quantitative (light, depth, atmospheric pressure) and others were categorical (fishing grounds, cloud cover, sea state, wind force, direction of swell, wind direction). The survey was conducted over two years, from 31 August 1993 to 27 November 1995, although not all boats actively fished for *Nephrops* during the entire period. Only the first morning haul (approximately 08:00–12:00 GMT) was considered for analysis in order to remove the effect of increased catchability at noon. Our own data indicate that burrow emergence activity (and hence catchability) increases around noon, confirming the hypothesis in Farmer (1975) that the dawn and dusk activity periods observed for shallow water *Nephrops* in high northern latitudes coalesce into a single midday peak on the upper slope (see also Chapman, 1980). After checking data for validity, 560 complete records were processed out of a total collection of 823 records (Table 2).

Statistical analysis

Catch data were transformed into cpue (kg h^{-1}). Trawl tracks were plotted on a map with the help of a GIS system (ArcView) to delineate specific fishing grounds. In all, 20 fishing grounds were visited during the study

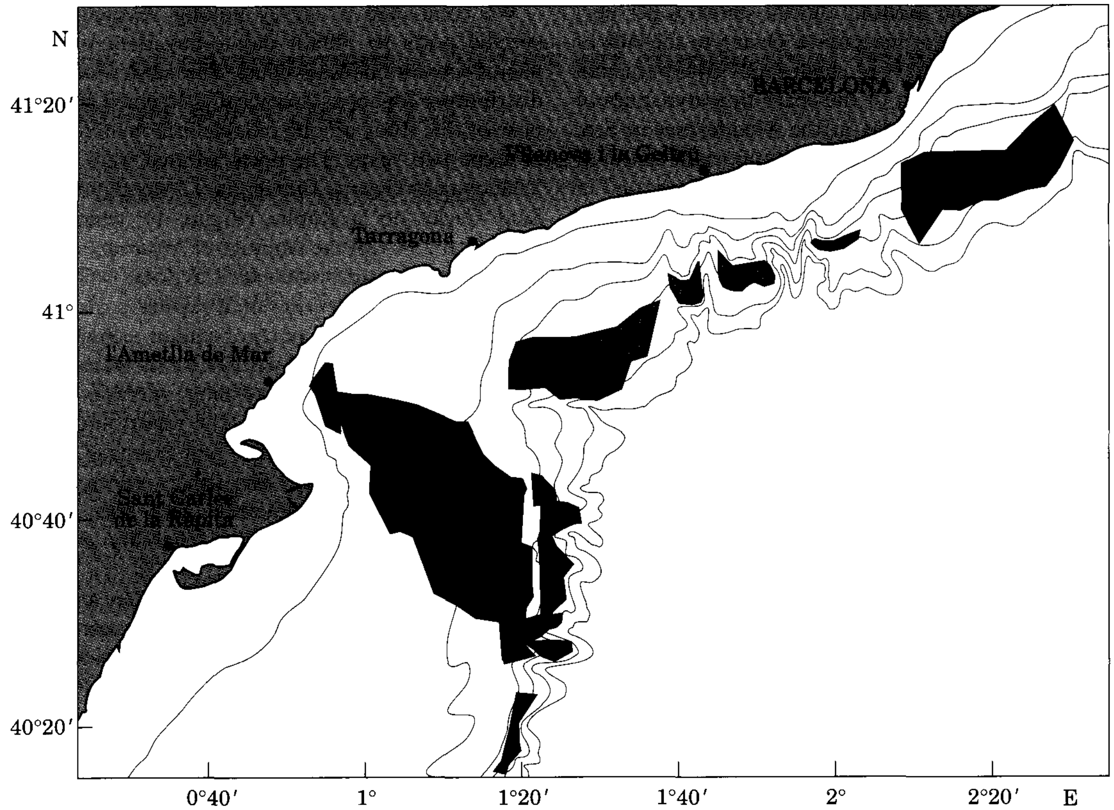

Figure 1. Map of the study area (central and southern Catalonia) showing location of the fishing ports sampled and the fishing grounds visited during the two-year study. Shades of grey indicate the fishing grounds visited by each commercial trawler (the boats of each port work only on the nearest fishing grounds). Depth contours shown are (in m): 50 (limit of the closed area to trawlers), 100, 200, 400, 600 and 800.

Table 1. Variables reported by fishers on specifically designed logbooks on a haul-by-haul basis.

Parameter	Record
Haul	Date Start and end times of trawling (GMT) Start and end positions of trawling (GPS) Start and end depth (m) Name of fishing grounds
Wind	Force [(three-point scale: calm, medium (≤4 knots), strong (>4 knots))] Direction (eight compass-point scale)
Sea	State (three-point scale: calm, rough, very rough) Swell direction (eight compass-point scale)
Atmospheric conditions	Light intensity (lumen) Cloud cover (two-point scale: clear, covered) Atmospheric pressure (mb)

period, covering most of the local distribution of the species (Figure 1). The fishing grounds were identified by fishers in their logbooks and incorporated in our analysis as a categorical variable. They indicate the general area of trawling, but they span a considerable depth range of the continental shelf and slope.

The quantitative environmental variables reported were used as explanatory variables in multiple regression analysis, with cpue as the dependent variable. The categorical variables wind force and direction, cloud cover, sea state, and swell direction were analysed by means of ANOVA/MANOVA techniques (with $p=0.05$ as the significance level). The influence of seismic movements on the variability of cpue was tested by comparing the cpue the week after an earthquake with the cpue the week before or during the earthquake, by means of ANOVA and by visual examination of the data. Only earthquakes felt by the general population (classified as "macro-seismic" activity in Generalitat de Catalunya (1993–1995), and corresponding to intensities III or higher on the MSK scale) were taken into account for the area studied, because these are the earthquakes perceived by fishers to provoke sudden decreases in cpue. Because tidal activity in the Mediterranean is low, catch rates do not vary over a lunar cycle, as in North Atlantic *Nephrops* stocks (Chapman, 1980).

Table 2. Fishing boats and periods sampled during the survey.

Boat	Port	Valid records	Sampling period
Maireta (1)	Barcelona	89	25/10/93–23/11/94
La Blava (2)	Vilanova i la Geltrú	144	02/09/93–27/10/95
Madobe (3)	Tarragona	105	20/07/94–21/09/95
Marisin (4)	L'Ametlla de Mar	178	31/08/93–31/03/95
Francisca Obiol (5)	Sant Carles de la Ràpita	44	01/09/93–04/08/95

Results

The data series obtained are shown in Figure 2. There is a clear lack of monthly or seasonal signal in each series and most of the cpue variability is due to day-to-day fluctuations. Even though the boats sampled focused primarily on the *Nephrops* fishery, data are lacking for relatively long periods (one to two months in some cases) owing to temporary shifts in a fisher's objective or other causes unrelated to the fishery (boat maintenance, engine repair, etc.).

An ANOVA considering the cpue of the five boats as the response variable and the fishing boat as the explanatory variable showed cpue to vary significantly among boats ($p=0.02$). A *post-hoc* Scheffé test indicated that the cpue of boats 1, 2, and 3 was not significantly different, whereas that of boat 4 was significantly lower than average, and that of boat 5 significantly higher than average. This difference between boats 4 and 5 and the other three boats can also be seen in Figure 2. The cpue of boat 4 was very low (typically <1 kg h^{-1}), whereas that of boat 5 was high (>6 kg h^{-1}). Fishing boats 1, 2, and 3 work on upper slope muddy substrata between 300 and 500 m deep off the central coast, whereas boats 4 and 5 operate out of the two southernmost ports, where the geomorphology of the continental margin and the substratum characteristics differ from those in the central area. Boat 4 operates over the shelf (65–105 m deep) on fishing grounds characterized by large lobsters with low density (cf. Maynou and Sardà, 1997), whereas boat 5 operates on fishing grounds 40 miles from port, where fishing pressure is low and yield is high. Most of the variability in the cpue of boat 4 (85%) was significantly explained by the category fishing grounds in an ANOVA ($p<0.01$). Boat 5 yielded no relationship between cpue and fishing location.

As the cpue of boats 1, 2, and 3 did not differ significantly, the data for the three vessels were analysed jointly by multivariate linear regression, taking cpue as the response variable and mean depth, tow length, light intensity, and atmospheric pressure as explanatory variables. Depth and atmospheric pressure explained 37% of the variance in cpue ($F_{4,183}=26.5$, $p<0.0001$, Table 3) for this group of three boats (Figure 3). The cpue of boats 4 and 5 showed no significant relationship with the variables tested in separate multivariate regression analyses ($p>0.05$ in both cases).

The MANOVA for boats 1, 2, and 3, taking the residuals of the cpue obtained in the multivariate regression analysis as the response variable, and sea state, swell direction, wind force, wind direction, and cloud cover as explanatory variables, revealed that cloud cover ($p<0.0390$) and sea state ($p<0.0010$) were two additional variables that contributed to explain the variation in cpue in the central area. Those two variables contributed a further 20% of the variance explained.

It is interesting that the cpue of boat 4, fishing in shallower waters, did not appear to be influenced by any environmental factor. Perhaps the heterogeneity within fishing grounds or the very low cpue values mask any relationship with environmental variables. The cpue of boat 5 had no significant relationship with the environmental data, perhaps because of the paucity of observations for that boat.

Combining the variance of cpue explained by the significant variables in the multivariate regression and the MANOVA model of the residuals for boats 1, 2, and 3, the results given here show that 57% of the variability in the daily cpue of *Nephrops* can be explained by environmental factors such as depth, atmospheric pressure, cloud cover, and sea state, at least in the central area where fishing was conducted on deep water (continental slope) fishing grounds. The cpue increased with depth and atmospheric pressure (Table 3), but decreased in cloudy conditions or in rough sea (Table 4).

In investigating the influence of seismic movements on variability in cpue, the results were inconclusive. Catch rates during the day and the week immediately following notable seismic activity were sometimes lower than the average cpue of the previous days, but they were never statistically different. However, this negative result does not definitively rule out seismic activity as influencing the catchability of benthic resources, because the number of such incidents in the study area is low (typically five to six per year during the period 1993–1995).

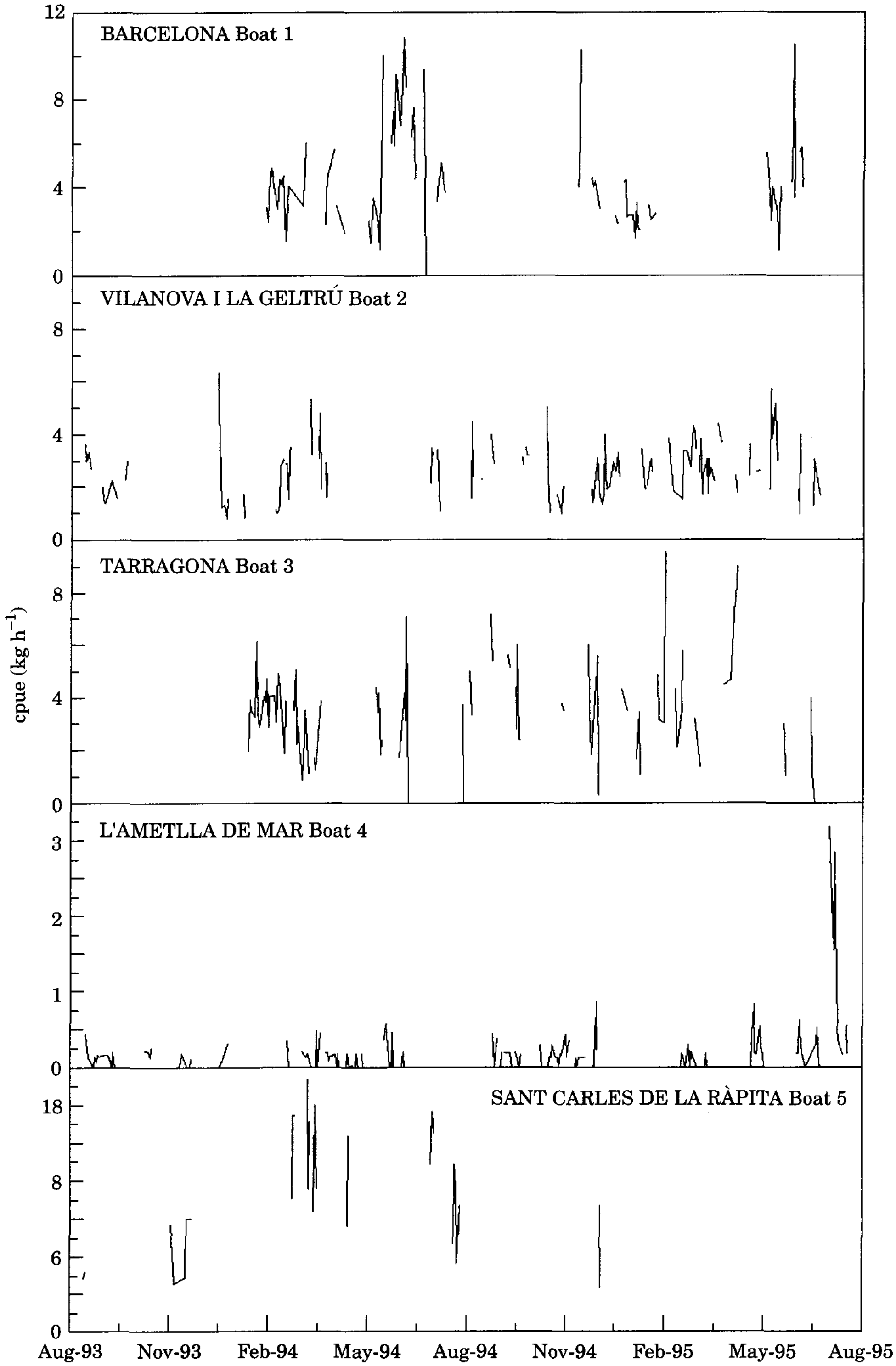

Figure 2. Catch rate (cpue) data series for each commercial boat surveyed. Note the high day-to-day variability and the lack of clear trends in the series.

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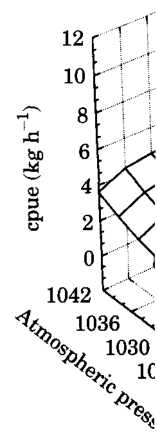

Figure 3. Results
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Discussion

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Table 3. Summary results of the multivariate regression analysis of group 1 boats (boats 1, 2, and 3) showing the response of cpue to environmental variables and their significance levels. Multiple $r^2=0.37$. The interaction terms between explanatory variables were not significant, except for the pair depth, e.g. light intensity ($p=0.02$), and were dropped from the analysis to facilitate interpretation of results.

Variable	Coefficient	p-value
Intercept	− 5.340	0.0002
Mean depth	0.028	<0.0001
Light intensity	0.062	0.5124
Atmospheric pressure	0.004	0.0030

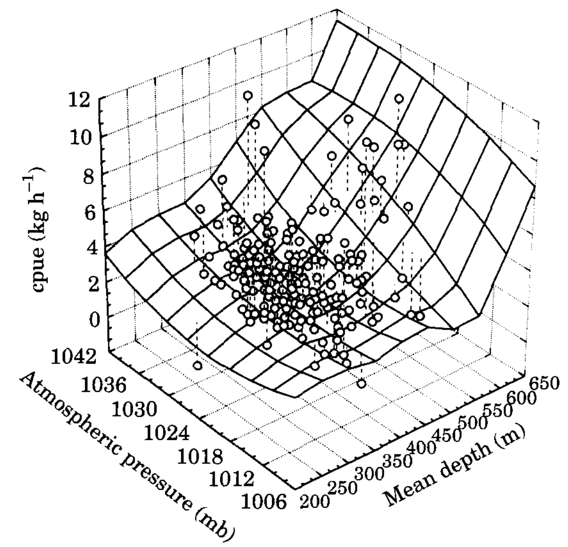

Figure 3. Results of the multiple regression analysis showing the relationship between depth, atmospheric pressure and cpue for boats 1, 2, and 3 in the central area, with the fitted response surface.

Table 4. Analysis of residual cpue from the multivariate regression (Table 3) for group 1 boats (boats 1, 2, and 3), showing the significance levels of additional environmental variables. Variance explained, 0.20.

Variable	p-value
Wind direction	0.9000
Wind force	0.7500
Cloud cover	0.0390
Sea state	0.0010
Swell direction	0.1500

Discussion

The results show that 57% of the variability in *Nephrops* cpue on deep water grounds can be explained by the environmental factors depth, atmospheric pressure, cloud cover, and sea state. Other factors, such as small-scale spatial heterogeneity within restricted depth ranges, probably also contribute to explain the remaining variability in cpue, as suggested by our results for the shallow-water fishing boat (boat 4, l'Ametlla de Mar), for which most of the variability was explained by the single factor fishing grounds, and other studies (Hillis, 1988; Tully and Hillis, 1995; Maynou and Sardà, 1997).

The commercial cpue of *Nephrops norvegicus* varies over spatial and temporal scales. It is likely that spatial heterogeneity can be attributed to spatial differences in the grounds occupied by burrowing species, such as substratum characteristic and depth (Chapman, 1980; Tully and Hillis, 1995; Maynou and Sardà, 1997). Temporal variability can be attributed to variability in atmospheric conditions, which probably alter the availability of a species to fishing gear, as reported by Perry *et al.* (2000) for inshore fisheries on *Pandalus jordani* off western Canada. On deep fishing grounds for *Nephrops norvegicus* (300–500 m off the central Catalan coast), brighter days (clear skies with high atmospheric pressure) and calm seas would allow greater penetration of light to the seabed, making the species more vulnerable to the fishing gear as it exits the burrow to feed. However, the variable light intensity, as measured by our fisher collaborators directly on their boats, was not significant in the multiple regression analysis. The catch rate of *Nephrops* is sensitive to variations in light intensity at the seabed (Hillis, 1996), but it is probable that light intensity measured at the sea surface is not directly related to that at the seabed, so additional information on water clarity would have been helpful for this analysis.

To explain the results given here, we propose that, on clear days in deep water (200–400 m deep), a larger fraction of the *Nephrops* population emerge from their burrows to feed and so become vulnerable to the trawl gear. This interpretation contrasts with that of Perry *et al.* (2000), who found that the cpue of *Pandalus jordani*, a highly mobile shrimp, diminished on bright days. The hypothesis of Perry and his co-authors was that this was due to net avoidance by the shrimp.

On the other hand, the lower catch rates obtained in rough seas can likely be explained, at least partially, by the diminished efficiency of the gear in such conditions, combined with bottom water currents that increase bottom turbidity in shallow water and hence decrease light intensity (Chapman, 1980; but see also Hillis, 1996).

The importance of taking fishers' observations into account in fisheries management has been debated by Mackinson and Nøttestad (1998). In this study, we found that the contribution of such information was significant when conveniently filtered and categorized in a manner that made it useful for scientific purposes. Some recent work analysing data contributed by fishers support this opinion (Freire and García-Allut, 1999). The Norway lobster fishery is an interesting case study, because *Nephrops* is a benthic species of low mobility and highly dependent on the availability of substrata appropriate for burrowing. Fishers are well informed of the species' distribution in high-density patches and can integrate different environmental variables in their minds, so believing that they can explain the variations in *Nephrops* catchability. However, the scientist must be careful in handling the data provided by fishers in studies such as this, because not all fisher beliefs can be translated into scientific hypothesis and, also, not all records contain valid information. For instance, fishers assert that, after strong storms, the cpue of *Nephrops* is low because the storm has disturbed the water and the sediment. However, because they are convinced of this idea they do not pursue the *Nephrops* fishery on days immediately after such storms, yielding no data for scientists to test. Also, fishers' belief that seismic activity influences cpue variability cannot be confirmed.

Additionally, over the two years of the study, many records were incomplete because of the carelessness of a fisher's recording, indicating that, even if the questionnaires are distributed among *a priori* reliable fishers, many fishers must be selected for interview, or else the fishers must be specially motivated, to ensure the success of this approach.

Not all hypotheses of fishers could be confirmed, possibly because of the limited time span of our study (two years). The long time span and the cumulative nature of fishers' memories makes them sensitive to the regularity of some environmental phenomena, which only become statistically significant when large data sets are analysed. An average fisher typically has 10–20 years in this specific fishery and his experience draws from personal observations as well as observations made by his forebears and other fishers in the same fishery. Integrating Traditional Ecological Knowledge in current assessment and management schemes is still a subject of active research (Freire and García-Allut, 1999).

Further research into factors affecting the vulnerability of *Nephrops* to trawl gear over short time scales would surely require analysis of the influence of light intensity at the seabed, particle flux in the water column, turbidity, and sediment disturbance on the seabed. These variables are technically complicated to measure and would require the assistance of marine geologists or hydrologists rather than fishers. On the other hand, the systematic use of a large number of fishers conducting daily field observations on fisheries ecosystems of the type presented here would surely improve understanding of the factors affecting catchability of fish at small scales. This information could be invaluable in improving assessment methods and management schemes.

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