Fishers' knowledge as an indicator of spatial and temporal trends in abundance of commercial fish species: Megrim (*Lepidorhombus whiffiagonis*) in the northern North Sea

P. Macdonald [a,*], C.H. Angus [a], I.R. Cleasby [a], C.T. Marshall [b]

[a] NAFC Marine Centre, Marine Science & Technology Department, Port Arthur, Scalloway, Shetland ZE1 0UN, UK
[b] University of Aberdeen, School of Biological Sciences, Zoology Building, Tillydrone Avenue, Aberdeen AB24 2TZ, UK

ARTICLE INFO

ABSTRACT

The need for alternative strategies to assist in the monitoring and sustainable management of many commercially important fish stocks is widely recognized. In recent years, greater utilization of fishers' knowledge has been advocated as a potentially valuable source of ecological data in the assessment and management process. In this study changes in the distribution and relative abundance of common megrim *Lepidorhombus whiffiagonis* in the North Sea were investigated by comparing three data sources: fishers' knowledge collected through a structured questionnaire; a vessel's haul-by-haul catch data from the personal diaries of a single skipper over a 10-year time-series, and catch rates from fishery-independent surveys (IBTS Q1 and Q3). Trends in the distribution and relative abundance of megrim were broadly comparable between the three data sources. The results of the study indicate that, in the northern North Sea, fishers' knowledge and catch data can provide valid data sources which can contribute to the assessment and management process. A structured approach consisting of a formal agreement, full transparency and commitment between all stakeholders is needed to provide and utilize the necessary data required to provide the most effective and inclusive approach to resource management.

1. Introduction

In 2011 the European Commission reported that analytical assessments are not available for 62% of fish stocks in European waters due to a lack of biological and ecological information about individual stocks, coupled with inaccurate or missing age catch data [1]. It is widely recognized that if this scenario is to improve new strategies are required to monitor and manage these common marine resources [2,3]. In recent years one alternative source of information on fish stocks that has been widely advocated is fishers' local knowledge [4–6]. Fishers, as a result of their extensive interaction with their surrounding environment and other fishers, often recognize long-term trends in fish populations and ecosystems and may be effective at tracking trends in fish stocks [7]. The majority of fishers are known to keep accurate records of catch composition and effort patterns, consequently gathering long-term distribution and abundance data for individual fish species that may extend beyond the chronological limit of scientifically collected data. Indeed, fishers often feel that their extensive knowledge and understanding

of fisheries should be taken into consideration during the process of managing fish stocks. Johnson [8] suggests that a two-way flow between fishers and scientists can improve management by incorporating and utilizing all available knowledge. Carr and Heyman [9] also suggest that fishers' knowledge can improve management in data-poor fisheries. However, the use of fishers' knowledge may have inherent problems due to what is seen as a professional asset being distributed to science and management [10].

A number of studies have been undertaken to examine the feasibility of applying fishers' knowledge in fisheries management. Foster and Vincent [11] utilized fishers' extensive knowledge to assist in recommending management measures for an unsustainable tropical shrimp fishery. Similarly, Zukowski et al. [12] noted that, in the Australian Murray crayfish (*Euastacus armatus*) fishery, local fishers' knowledge could detect population changes at an early stage, allowing adaptive management. Furthermore, Lorance et al. [13] were able to identify regional management issues and solutions in a number of European deep-water fisheries using stakeholder knowledge collected through a structured questionnaire. The relevance and validity of fishers' knowledge has also been examined in relation to ecosystem studies. Bergmann et al. [14] reported that fishers in the Irish Sea were able to provide biological observations that were useful in supplementing knowledge of essential fish habitats. A similar study in the

* Corresponding author. Tel.: +44 1595 772331; fax: +44 1595 772001.
E-mail address: paul.macdonald@uhi.ac.uk (P. Macdonald).

eastern English Channel noted that fishers' perceptions of ecosystem changes were consistent with scientific data [15].

In northern Europe, the common megrim, *Lepidorhombus whiffiagonis*, a commercially important flatfish with a distribution extending from the Mediterranean Sea to Iceland [16], is an example of a data-limited species. The International Council for the Exploration of the Seas (ICES) considers two stock units of megrim on the Northern Shelf (*L. whiffiagonis* and *Lepidorhombus boscii* are considered together): one in Divisions IVa and VIa (northern North Sea and west of Scotland, respectively) and one in Subarea VIb (Rockall) [17,18]. In recent years the commercial relevance of megrim, especially in the northern North Sea, has increased significantly and it is currently one of the most important species by value landed into Scotland [19].

Megrim have a depth range of 50–850 m, although they are reportedly more common in depths around 200 m [20]. Historically, catches have been largely confined to the deeper water habitat along the continental shelf edge. In recent years however, fishermen engaging in the multispecies demersal fishery in the northern North Sea have reported changes in the distribution and abundance of megrim in the area, especially in the waters around the Shetland Isles [21]. The distribution of the species is currently perceived by many fishermen to have increased, spreading further east and south of the Shetland Isles into the northern North Sea. Fishermen have also reported an increase in abundance of the species throughout its distribution in IVa [21]. These perceived changes, coupled with a lack of increase in quota in recent years, have led fishermen to argue that current quota limits are overly restrictive and do not reflect perceived changes in distribution and abundance of the species in the recent past. A recent study reported that discarding of megrim by vessels engaged in the mixed demersal fishery around the Shetland Isles has been as high as 70% [21], largely due to quota restrictions.

Quantitative management advice produced by ICES for megrim in Divisions IVa and VIa is currently provided by a Bayesian state-space biomass dynamic model utilizing indices from fishery-independent surveys and landings data [22]. One of the fishery independent survey indices utilized in the assessment is the biannual North Sea International Bottom Trawl Survey (NSIBTS) [23]. In the northern North Sea the survey is undertaken during the first and the third Quarters by eight participant countries. The main objective of the NSIBTS is to provide recruitment indices of a defined list of commercially important fish species. Further to this, the survey also allows changes in the stock size of a number of commercial fish species to be monitored. However, one of the disadvantages inherent with the use of survey data is limited spatial and temporal resolution. In the case of the NSIBTS, distribution and abundance estimates are limited to a biannual 'snapshot'. NSIBTS sampling can be limited to as little as one sample per ICES statistical rectangle, with each rectangle representing approximately 110 km^2. In contrast, fishers' sample fishing grounds on a regular basis, thereby collecting temporally resolved data on fish abundance and distribution. Therefore, accessing fishers' knowledge and data has the potential to provide increased spatial and temporal resolution that can, if provided in an appropriate format, be utilized within the assessment process. It also has the potential to validate fishery-independent survey trends and provides fishers' with the opportunity to be actively engaged in the provision of data for improved resource management.

The aim of this study was to determine whether Scottish fishing skippers' perceptions about, and personal catch data on, megrim distribution and relative abundance in the northern North Sea in recent years was consistent with trends in a fishery-independent survey index estimated from the biannual NSIBTS. Fishing skippers' perceptions about distribution and relative abundance were quantified through a structured questionnaire. An individual vessel's catch data was transcribed from haul specific catch diaries over a 10-year period. Time-series analysis was undertaken on NSIBTS data from 1971 to 2010 for the Quarter 1 survey and 1991 to 2009 for Quarter 3.

The applicability of fishers' local ecological knowledge as a means to improving fisheries management is discussed.

2. Materials and methods

The study was undertaken in the northern North Sea (ICES Division IVa). ICES Division IVa extends from latitudes 57°30′N to 62°00′N and from longitudes 004°00′W to 007°00′E. It extends from the edge of the continental shelf north-west of the Shetland Isles into the fjords along the coast of Norway in the east, encompassing the Shetland and Orkney Isles as well as the north-east coast of Scotland. The study area was representative of fishing grounds frequented by Scottish vessels rather than the entire ICES Division IVa. In order to gather more localized information the study area within IVa was divided into six illustrative areas (Fig. 1).

2.1. Fishers' knowledge questionnaire

In order to gather fishers' knowledge, a questionnaire, comprising three sections, was constructed (Table 1). Section 1 (vessel descriptors) was structured to gather information on the survey participant, including information on the experience of the skipper, the vessel, gear type, fishing grounds and target species. Section 2 (fishing tactics) was designed to investigate fishing tactics employed by individual skippers. Finally, Section 3 (megrim) was designed to gather skippers' knowledge on changes in megrim distribution and abundance in the northern North Sea. A section was provided at the end of the questionnaire for skippers to add comments.

A copy of the questionnaire, a covering letter and return envelope were mailed in May 2010 to 261 individual skippers who fished in the mixed species demersal fishery in the northern North Sea. The mailing list included all Scottish vessels fishing in the northern North Sea irrespective of whether they targeted megrim consistently,
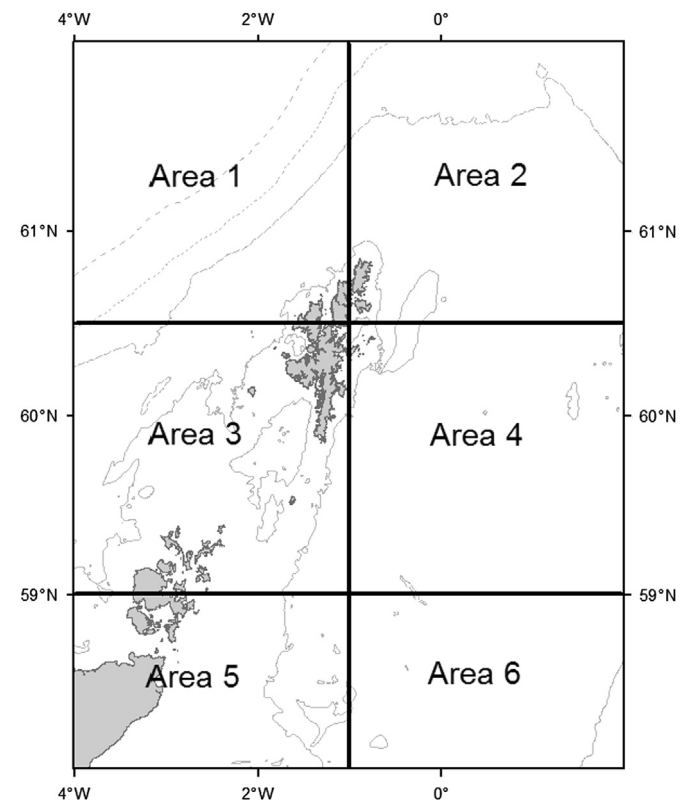

Fig. 1. Study area divisions used in the fishers' knowledge survey, analysis of diary data and NSIBTS data.

Table 1
Questions and response options for fishers' knowledge questionnaire.

Question	Responses
Vessel descriptors	
How long have you been the skipper of this vessel?	Less than 1 year
	Between 1 and 5 years
	Between 6 and 10 years
	More than 10 years
What size is your vessel?	Under 10 m
	10–12 m
	12–15 m
	15–25 m
	Over 25 m
What type of gear do you fish with for the majority of the year?	Seine net
	Single rig otter trawl
	Twin rig otter trawl
	Other
How long does a typical fishing trip last?	Less than 1 day
	2–5 days
	6–7 days
	More than 7 days
How important are each of the following species (monkfish, haddock, cod, whiting, megrim, saithe, ling) to your annual catch?	Very important
	Important
	Less important
	Not important
Fishing tactics	
How often do you fish in each of the six illustrative areas?	Very often
	Often
	Not often
	Never
What influence does available quota have on your choice of fishing grounds?	Absolutely determines where I fish
	Plays an important role in determining where I fish
	Is part of a wider process to determine where to fish
	Does not affect where I choose to fish
What influence did quota have on your choice of fishing grounds when you first became a fishing skipper?	Absolutely determined where I fished
	Played an important role in determining where I fished
	Was part of a wider process to determine where to fish
	Did not affect where I chose to fish
Megrim	
How often is megrim one of your main target species?	Throughout the year
	Seasonally
	Rarely or never
Do you believe the quantity of megrim in the northern North Sea in recent years has:	Increased
	Decreased
	Stayed the same
Do you believe the spread of megrim in the northern North Sea in recent years has:	Increased
	Decreased
	Stayed the same
In general terms, what would you expect the catch per unit effort of megrim to be in each of the 6 areas at present?	Very high
	High
	Average
	Low
	Do not know
In general terms, what do you believe the catch per unit effort for megrim was in each of the 6 areas when you first became a fishing skipper?	Very high
	High
	Average
	Low
	Do not know
Do you believe catches of megrim in the northern North Sea in recent years have generally:	Increased
	Decreased
	Stayed the same
If you answered 'increased' above, how significant do you think each of the following factors have been to the recent increases in megrim catches (very significant, significant, less significant, not significant, don't know)?	Available quota
	Changes in fishing grounds
	Changes in target species
	Greater numbers of megrim on the grounds
	Changes to fishing gear
	Presence of megrim in areas not previously seen

seasonally, or not at all. Skippers' contact details were provided by the Scottish Fishermen's Federation.

All questions were provided with multiple choice answers consisting of between three and five response options. Responses were designed using a Likert-type scale [24]. The Likert scale is a one-dimensional scale from which respondents choose the option which best fits with their views. Questionnaire responses were ranked on a numerical scale for further analysis. Data were analyzed using the

Kruskal–Wallis one-way analysis of variance by ranks to investigate differences between scores within categories i.e. questions. The Mann–Whitney *U* test was used to determine whether significant differences existed in scores between categories.

Sixty-two of the 261 questionnaires (24%) were returned completed. A further eight skippers reported that vessels had been sold, target species had changed (i.e. to shellfish), or retirement from the industry.

2.2. Fisher's catch data

LPUE (landed fish per unit effort) data were transcribed from the diary of a single mixed species demersal trawler (26.6 m, 241 gross tonnage) that has consistently fished a single net rig demersal trawl around the Shetland Isles between 2000 and 2009. Hauls were undertaken throughout the year for each of the years considered. The duration of each haul varied from 5 to 6 h. Data were recorded in the diary as the number of boxes of gutted megrim per haul. The weight of megrim in a box was assumed to be consistently 30 kg throughout the study. For the purpose of the analysis undertaken here, LPUE was converted from boxes per haul to kg/h. LPUE was calculated and averaged for each area (Fig. 1) over each year of the study. Data for each area were analyzed using the Kruskal–Wallis one-way analysis of variance by ranks to investigate differences between categories i.e. years. The vessel fished a standard single trawl with 120 mm codend. The main target species over the study period were cod, haddock, whiting and saithe, with megrim predominantly a by-catch species.

2.3. NSIBTS survey data

Survey data were downloaded from the ICES DATRAS (DAtabase of TRAwl Surveys: http://datras.ices.dk) database in October 2010. Data were selected from the NSIBTS Quarter 1 (Q1) and Quarter 3 (Q3) surveys. Due to the spatial coverage of the survey, data were considered for the period 1977–2010. Q3 data were available and downloaded for the period 1991–2009. Q3 data for 2010 were not included as the fishers' questionnaire was undertaken prior to this.

International Bottom Trawl Survey data contained a number of recognized 'health' warnings regarding quality and appropriate usage. Inherent weaknesses associated with the data include; differences between surveys that limit the ability to combine data between surveys; no guarantee that survey gear deployed adequately samples all species; and changes to survey sampling procedures, gear design and survey timing. Over the survey period the majority of tows were undertaken using the GOV (Grande Ouverture Verticale) trawl. Data for Q1 were collected using a GOV trawl by all participating nations from 1985 to 2010. Prior to 1985 a number of different trawls were used by different nations and, although designs may be similar, catchability may have varied between trawls. Data for Q3 were collected using the GOV trawl by all participating nations from 1998 to 2010. Prior to 1998 RV Scotia deployed the Aberdeen trawl and prior to 1992 a number of different trawls were deployed by different nations. It should also be noted that data on the type of ground gear deployed with each trawl is not available and may vary between nations and trawl types. The type of ground gear deployed on a trawl can have an effect on the species assemblage captured in the net, and this may result in variable bias in the data. The effect of changes in ground gear on estimates of catchability has not been examined in detail [25]. However, the usage of data in this study is not intended for comparisons between IBTS survey areas or provision of accurate estimates in abundance but rather to investigate trends in distribution and relative abundance.

Following extraction from the DATRAS database, catch per unit effort (CPUE) data were recorded for individual ICES statistical rectangles for each Quarter of each year of the survey. In many instances an individual statistical rectangle was sampled on more than one occasion in a given Quarter. When this occurred, the mean CPUE was calculated and used.

Data were converted into shapefiles using ArcMap 10 GIS software in preparation for visual analysis. Maps showing survey CPUE for each of the statistical rectangles sampled in the study area were produced for each of the years that survey data were available.

For the purpose of comparing temporal trends in survey distribution and relative abundance with fishers' perceptions, the time-series data within each of the six areas represented in Fig. 1 were analyzed. CPUE data from individual ICES rectangles were grouped within each of the six areas for each year and, as the grouped data were not normally distributed, the median annual values were used in the analyses. Analyses were undertaken on data from Areas 1–4 while the data available for Areas 5 and 6 were unsuitable to carry out analyses due to annual median values of zero for every year of the time-series.

Prior to analysis the time-series data from each area were inspected for auto-correlation using the auto-correlation (ACF) and partial auto-correlation (PACF) function. Plots of each time-series were also used to determine whether the time-series was stationary. A time-series is said to be stationary when its joint probability distribution does not change when shifted in time [26]. As a result, parameters such as the mean and variance of the series do not change over time. There was strong evidence of non-stationarity in both Areas 1 and 2 so ARIMA (auto-regressive integrated moving average) models were fitted to these time-series'. An ARIMA (p, d, q) model has three components p, d and q which correspond to the order of the auto-regressive, integrated and moving average component of the model, respectively. Integration is used in time-series modeling to transform a non-stationary time-series into a stationary one by differencing it (subtracting previous values from the current value). Stationarity of the time-series is an important assumption of traditional ARMA models, hence the need for integration. For Areas 1 and 2 a first order integration appeared to give stationary time-series. Inspection of the ACF and PACF plots for these integrated time-series suggested that an order 1 moving average process was suitable to model the auto-correlation in both cases. Therefore, ARIMA (0,1,1) models were fitted to the time-series from Area 1 and Area 2 using the R package 'TSA' [27]. Other possible ARIMA structures were tested, but the original (0,1,1) model was retained as it had the lowest AIC score. To estimate the trend in the time-series each year in the study was numbered sequentially and included as a covariate within the ARIMA model [26].

Due to the large number of zeros in the Areas 3 and 4 time-series it was judged that ARIMA models would not be appropriate for these areas. Instead a zero-inflated poisson hurdle model was fitted to the data to account for the number of zeroes in the Areas 3 and 4 time-series. Zero-inflated hurdle models are mixture models that use a binomial probability model to assess whether a count has a zero or a positive value. If the value is positive then a hurdle is crossed and the distribution of positive values is fitted to a zero-truncated count model. To estimate the trend in these time-series a data vector was created that numbered each year sequentially and included this as a predictor in the hurdle model. To account for the time-series nature of the data a Newey–West estimator using the R package 'sandwich' [28,29] was used. The Newey–West estimator is a type of sandwich estimator that can be used to account for auto-correlation within a time-series. Here, a Newey–West estimator with a lag of 1 was specified for both time-series based on PACF plots. The Newey–West estimator also has the additional advantage that it will account for any heteroscedasticity in both time-series, which could influence the standard error estimates from the model [30]. It was specified that both time-series should be pre-whitened when using the Newey–West estimator using the in-built functions in the 'sandwich' package. Pre-whitening involves filtering the data to generate a white noise process, which was necessary because the original time-series'

were non-stationary [31]. All data analysis was undertaken in R statistical software package [32].

Finally, a Spearman rank-order correlation test was used to determine how well fishers' average annual catch data and median annual NSIBTS survey data (both Q1 and Q3) correlated in each of the illustrative sample areas where data were available.

3. Results

3.1. Fishers' knowledge questionnaire

3.1.1. Vessel descriptors

The largest percentage of respondents (87%) were skippers having more than ten years of experience in the industry. Respondents were predominantly fishing with vessels in the size range 15–25 m (79%) with a further 16% of returns from vessels greater than 25 m. The returns by gear type were highest for twin trawl vessels (52%) while 24% were from single trawl vessels, 15% from seine net vessels and the remaining 9% from vessels fishing with pair trawls. The length of fishing trips undertaken by respondents was predominantly 6–7 days (45%) while 34% undertook trips lasting more than 7 days. The largest single group of respondents (37%) were skippers with more than 10 years of experience fishing twin trawl gear with vessels in the size range 15–25 m.

Megrim was not considered to be the most commercially important species to fishers. The relative importance of the seven main commercial demersal species (monkfish, haddock, cod, whiting, megrim, saithe and ling) was significantly different (Kruskal–Wallis $H=35.25$, $df=6$, $P<0.001$) across vessels with monkfish and haddock reported as being the most important species commercially, followed by cod. Whiting, megrim and saithe were considered less commercially important and ling was the species having the least commercial importance.

3.1.2. Fishing tactics

Skippers were asked to report how much time they spent fishing in each of the six areas shown in Fig. 1. There was a significant difference in the amount of time spent fishing in the six areas (Kruskal–Wallis $H=26.96$, $df=5$, $P<0.001$) with respondents spending more time fishing in Areas 2–4 than in Areas 1, 5 and 6.

Respondents were asked to compare what effect the quota system has on their choice of fishing grounds at present, compared with when they first became a fishing skipper. Available quota was found to play a significantly greater role in determining where vessels fish presently than it did in the past (Mann–Whitney $U=2251.5$, $P<0.001$) with 85% of skippers reporting that availability of quota plays an important or essential role in determining where they choose to fish now. Conversely, 85% reported that quota had little effect on where they chose to fish when they first became skippers.

3.1.3. Megrim

Respondents consisted of a varied group of vessels with respect to the targeting of megrim. Twenty-three percent targeted the species throughout the year, 38% on a seasonal basis and 39% rarely or never.

Seventy-two percent of skippers returning surveys believed that the overall distribution of megrim in the northern North Sea has increased in recent years. Twenty-three percent believed it has stayed the same and 4% believed it has decreased. Skippers had similar views on changes in the abundance of megrim in the recent past with 69% reporting an increase in abundance, 26% reporting no change in abundance and 5% an overall decrease.

Skippers' expectations of megrim CPUE at present and when first becoming a fishing skipper are outlined in Fig. 2. There was a significant difference in the current megrim CPUE expectation between each of the six areas highlighted in Fig. 1 (Kruskal–Wallis $H=120.87$, $df=5$, $P<0.001$). Eighty percent of skippers expect megrim CPUE to be 'very high' or 'high' in Area 2 at present. The expectation for 'very high' and 'high' CPUE in Areas 1, 3 and 4 were 48%, 60% and 32%, respectively. Many of the skippers reported that they were unaware of what the megrim CPUE would be in Areas 5 and 6 both presently (31% and 46%, respectively) and when first becoming skippers (41% and 44%, respectively) although CPUE was typically ranked as 'low' for those that did respond.

There was also a significant difference in the perceived CPUE of megrim between the six areas when fishermen first became skippers (Kruskal–Wallis $H=89.34$, $df=5$, $P<0.001$). Forty-six percent of skippers expected megrim CPUE to be 'very high' or 'high' in Area 2 when first becoming fishing skippers. The expectation for 'very high' and 'high' CPUE in Areas 1, 3 and 4 were 42%, 39% and 14%, respectively. There was no significant change perceived in CPUE in Area 1 (Mann–Whitney $U=1775.5$, $P>0.05$), Area 5 (Mann–Whitney $U=1241.0$, $P>0.05$) and Area 6 (Mann–Whitney $U=801.5$, $P>0.05$) between the present and when respondents first became skippers. Furthermore, respondents reported an increase in megrim CPUE at present compared with when they first became skippers for Area 2 (Mann–Whitney $U=1653.5$, $P<0.001$), Area 3 (Mann–Whitney $U=1873.0$, $P<0.01$) and Area 4 (Mann–Whitney $U=2086.0$, $P<0.01$).

Respondents were asked how they perceived general trends in overall catches of megrim in the northern North Sea. Seventy-two percent reported that overall catches are generally increasing, 20% reported that they are neither increasing nor decreasing and 8% reported a decrease. Those that perceived an increase were asked to further elaborate on what they felt were the apparent causes of the increase. There was a significant difference in the perceived effects of the different factors on megrim catches (Kruskal–Wallis $H=33.83$, $df=5$, $P<0.001$) with the most significant factors affecting the increase in catches reported as 'megrim in areas not previously seen' and 'more megrim on the grounds' (Fig. 3). Available quota was seen as the next most important factor contributing to increased catches followed by changes in fishing grounds and changes in target species. Changes in fishing gear were reported as the least significant of the six factors contributing to increased catches.

3.2. Fishers' catch data

Fishing effort, as transcribed from diary entries, was predominantly distributed in Areas 1, 2 and 4 (Fig. 1), with 28%, 50% and 17% of the total effort over the 10 year time-series allocated to each area, respectively. The remaining 5% of fishing effort was allocated between a number of other fishing grounds within Areas 3, 5 and 6, and out with the overall study area. The average annual megrim LPUE for each of the three areas is outlined in Fig. 4. LPUE in Area 1 fluctuated but remained relatively constant at 0.5 kg/h for the first 7 years of the study and then increased significantly (Kruskal–Wallis $H=29.72$, $df=9$, $P<0.001$) to 1.1–1.4 kg/h during 2007–2009. In Area 2, there was also a significant increase in megrim LPUE over the study period (Kruskal–Wallis $H=74.92$, $df=9$, $P<0.001$). LPUE fluctuated from 0.7 to 1.0 kg/h from 2000 to 2003 and then exhibited a more progressive increase from 2004 onwards, peaking at 2.0 kg/h in 2009. LPUE in Area 2 was consistently higher than in Area 1 throughout the study period. Area 4 exhibited the largest degree of variation in LPUE over the study period. The lowest annual LPUE of 0.3 kg/h was evident in 2003. This was followed by a subsequent overall significant increase (Kruskal–Wallis $H=62.33$, $df=9$, $P<0.001$) until 2009, where there was a considerably higher average LPUE of 3.2 kg/h.
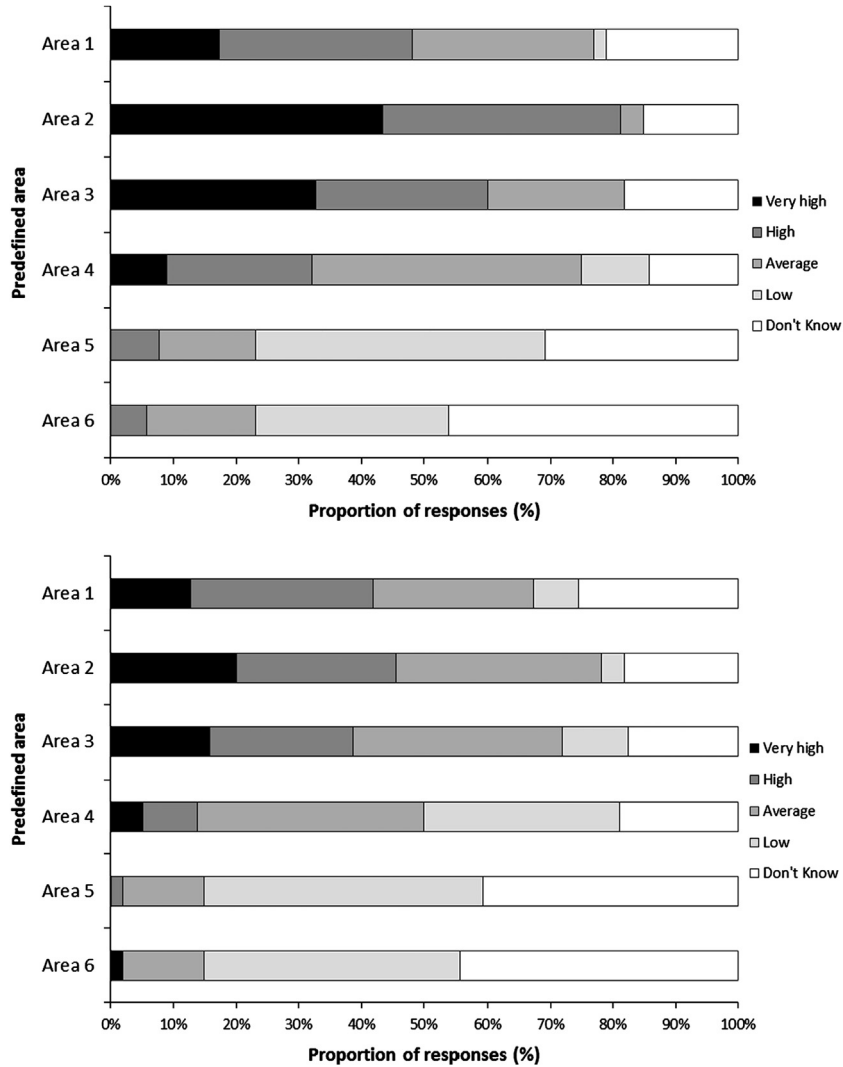
Fig. 2. Fishermen's expectation of catch per unit effort (CPUE) of megrim in six survey study areas of the northern North Sea. Top: CPUE expected at present and bottom: CPUE expected when first becoming fishing skipper (number of responses=58).
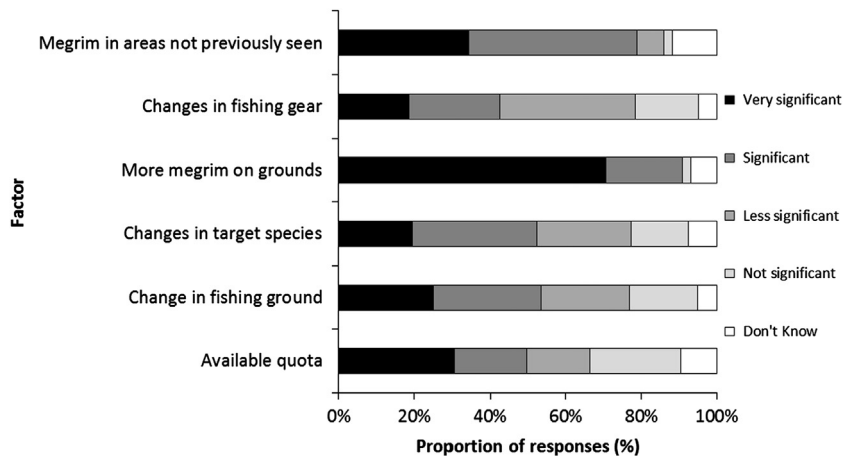

Fig. 3. Fishermen's perceptions on the significance of a number of factors to increased catches of megrim in the northern North Sea (number of responses=45).

3.3. Trends in survey data

Time-series plots of the distribution and abundance of megrim from Q1 and Q3 surveys are shown in Figs. 5 and 6, respectively.

Visual inspection of both time-series indicates an increase in survey catches of megrim south and east of the Shetland Isles into the northern North Sea in recent years. Q1 survey data shows limited variation in abundance and distribution from 1977 to 2002. The
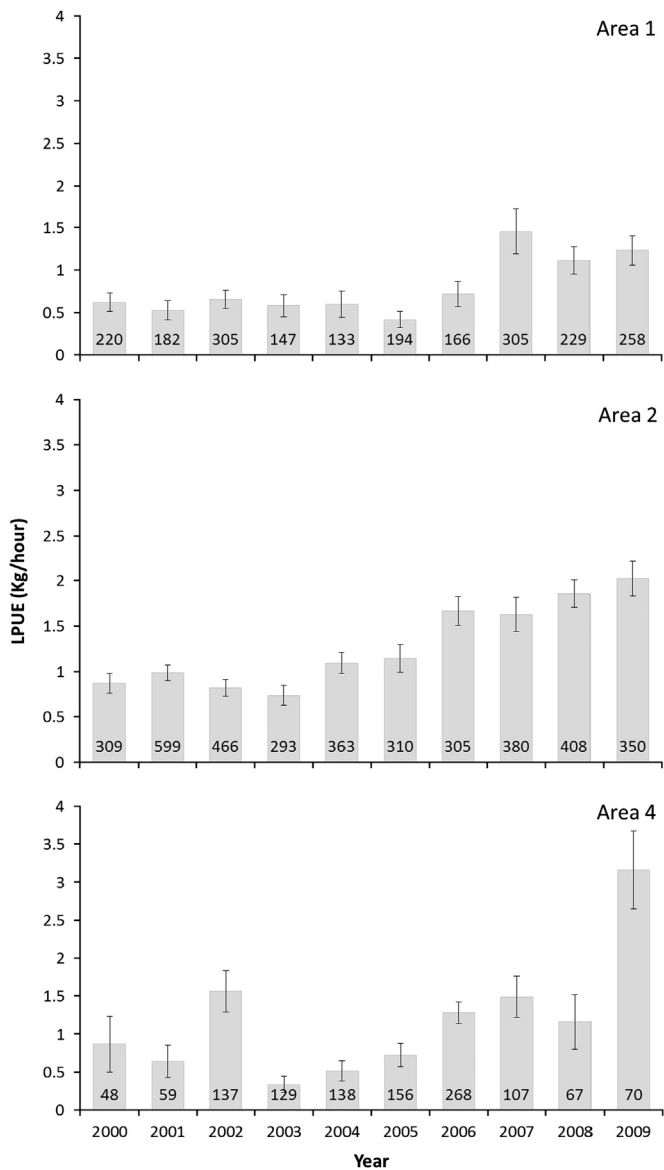
Fig. 4. Average annual megrim LPUE for a single trawl vessel in three study areas within the northern North Sea from 2000–2009 (± s.e. bars and number of hauls for each year are also shown).

highest survey catches during this period were consistently to the north and east of Shetland in Area 2. This was followed by a steady increase in abundance and distribution to the south and east of Shetland, especially in Area 4. In Q3 the increasing trend in survey catches in the North Sea basin, specifically in Areas 2 and 4, is more pronounced than in Q1. A similar trend of limited variation is seen between 1991 and 2002, followed by a steady increase in abundance and distribution until 2009.

Trends in survey catches for Q1 and Q3 in each of the six areas outlined in the fishers' questionnaire are shown in Figs. 7 and 8, respectively. In both surveys median values from Area 1 exhibit large annual fluctuations and there were no significant trends evident in either the Q1 or Q3 survey data (Table 2). Catches in Area 2 during the Q1 survey fluctuated over the time-series with a significant increasing trend ($P < 0.05$) in recent years (Table 2). Q3 data for Area 2 exhibited a more pronounced increasing trend ($P < 0.05$) with less fluctuation between annual values. Catch values in both Q1 and Q3 were relatively low in Area 3 throughout the time-series and although there were slight increases in CPUE in recent years there is no evidence of a significant trend (Table 2). Area 4 shows a trend of

increasing CPUE ($P < 0.05$) in both Q1 and Q3 data. In each case there were very low catches prior to 2002 followed by increases in the latter years of the study.

3.4. Comparison of survey and diary data

There was a moderate correlation between fishers' annual average catch data and NSIBTS Q1 data for Area 1 ($r = 0.64$, $P < 0.05$) and Area 2 ($r = 0.75$, $P < 0.01$). In Area 2 there was a strong correlation between fishers' annual average catch data and NSIBTS Q3 data ($r = 0.96$, $P < 0.001$). However, there was a weak correlation between fishers' data and NSIBTS Q3 data for Area 1 ($r = 0.12$, $P > 0.05$). Finally, there was a moderate correlation between fishers' catch data and both Q1 ($r = 0.59$, $P = 0.05$) and Q3 ($r = 0.62$, $P = 0.05$) NSIBTS data for Area 4.

4. Discussion

The results of this study indicate that fishers' perceptions of changes in distribution and abundance of megrim in the northern North Sea are consistent with spatial and temporal trends evident in survey data. NSIBTS survey data showed an increase in abundance to the east of Shetland in Areas 2 and 4 and this was consistent with fishers' perceptions of increased abundance in these areas. The ten year time-series of catch rates from diary data has also highlighted significant increases in relative abundances of megrim in Areas 2 and 4.

There was a significant increase in catches reported from diary data in Area 1 in the latter years of the study, albeit to a lesser degree than Areas 2 and 4. However, there was no significant increase evident in Area 1 in either the fishers' questionnaire or the NSIBTS survey data. Perceived increases in abundance highlighted by the fishers' questionnaire and catch data in Area 3 were also less pronounced in the survey data, with the time-series only showing a slight increase in more recent years. The differences between fishers' perceptions, catch data and survey abundance in Areas 1 and 3 may be due to spatial differences between survey stations and commercially important grounds. Catches of megrim west of Shetland are known to be higher in the deeper water along the shelf edge [33]. The proportion of Area 3 that includes shelf edge fishing grounds is markedly less than Area 1, and, while fishers' catches of megrim are greater along the shelf edge, the survey data is more representative of the entire area. It is, therefore, probable that increased catches along the shelf edge may not necessarily be representative of abundance within the entire area.

Trends in survey data, fishers' perceptions and diary data suggest an increase in abundance and distribution in the northern North Sea basin in recent years, although these increases are more pronounced east of the Shetland Isles. This may be indicative of an increase in the species' range in recent years due to increasing abundance in the northern North Sea. Fishers' have also noted that, in recent years, megrim have been captured in shallower water than previously expected (Johnson, 2010, personal communication). Density-dependent dispersal, driven by factors such as competition and population size, into less favorable environments [34] is one factor that may have led to changes in megrim distribution and greater relative abundance in the shallower water of the North Sea basin. Increases in abundance in recent years are evident in both the Q1 and Q3 NSIBTS data series, highlighting the fact that the increases have not been on a seasonal basis i.e. migration of fish to spawning or feeding grounds.

The proportion of respondents to the fishers' knowledge survey (24%) was relatively good, especially in comparison to similar surveys sent to fishermen. For example, respondents to the annual Fishers' North Sea Stock Survey (an annual survey of Fishers'
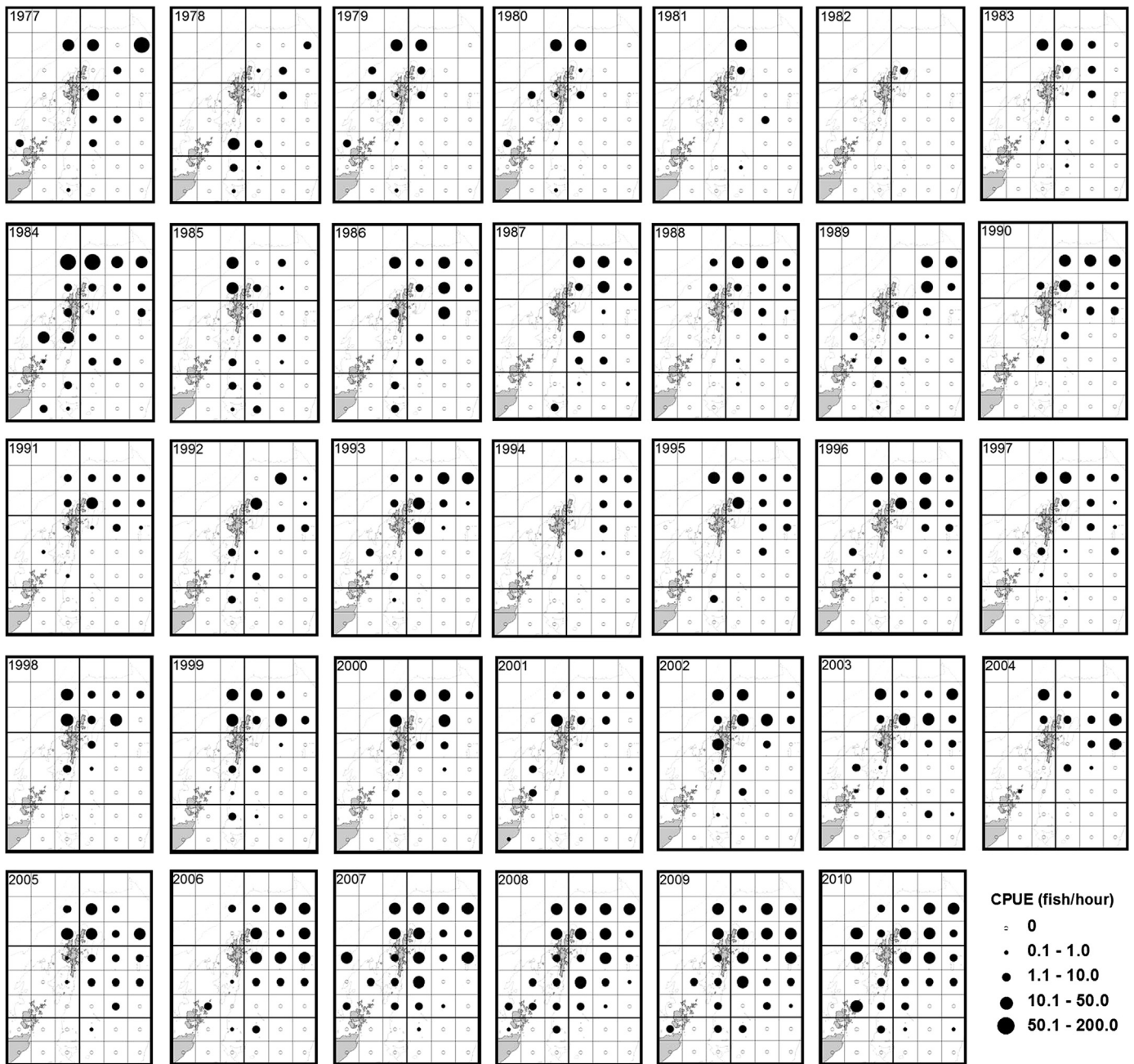
Fig. 5. Distribution and relative abundance of *L. whiffiagonis* in ICES Sub Area IVa from 1977 to 2010.
Source: North Sea International Bottom Trawl Survey (NSIBTS) Quarter 1.

perceptions of the state of fish stocks in the North Sea) from Scottish fishing skippers, are typically less than 12% (Napier, personal communication). In this survey fishermen are asked to record their perceptions of how the abundance, size range, discards and recruitment of eight commercially important species have changed from the previous year. The megrim survey undertaken in the present study was sent out to all members of the Scottish Fishermen's Federation fishing within the whitefish fishery in the North Sea, irrespective of whether megrim was one of their target species. The proportion of respondents from fishers targeting megrim was, therefore, relatively higher than the 24% overall response and possibly highlights the importance of this issue to these fishers. Skippers that declined to respond may have done so for a number of reasons including; megrim not being an important species to them (i.e. *Nephrops norvegicus* trawlers),

fishing in areas with low megrim abundance, or concentrating effort on other species such as haddock. There may also be a proportion that were not willing, or had no desire, to engage in the survey. However, there is no reason to suggest that their perceptions of megrim distribution and abundance would be different to those that did respond. The majority of respondents were skippers with more than 10 years' experience and, given the fact that the greatest increases in distribution and abundance occurred in the previous 10 years, the majority of skippers have experienced most, if not all, of these increases first hand.

The fishers' general perceptions on the distribution and abundance of megrim were validated by fishers' diary data. The diary data presented here represents a unique data set with a consistent haul-by-haul account of LPUE over a ten year period. However, one limitation of the diary data presented here is that it is restricted to
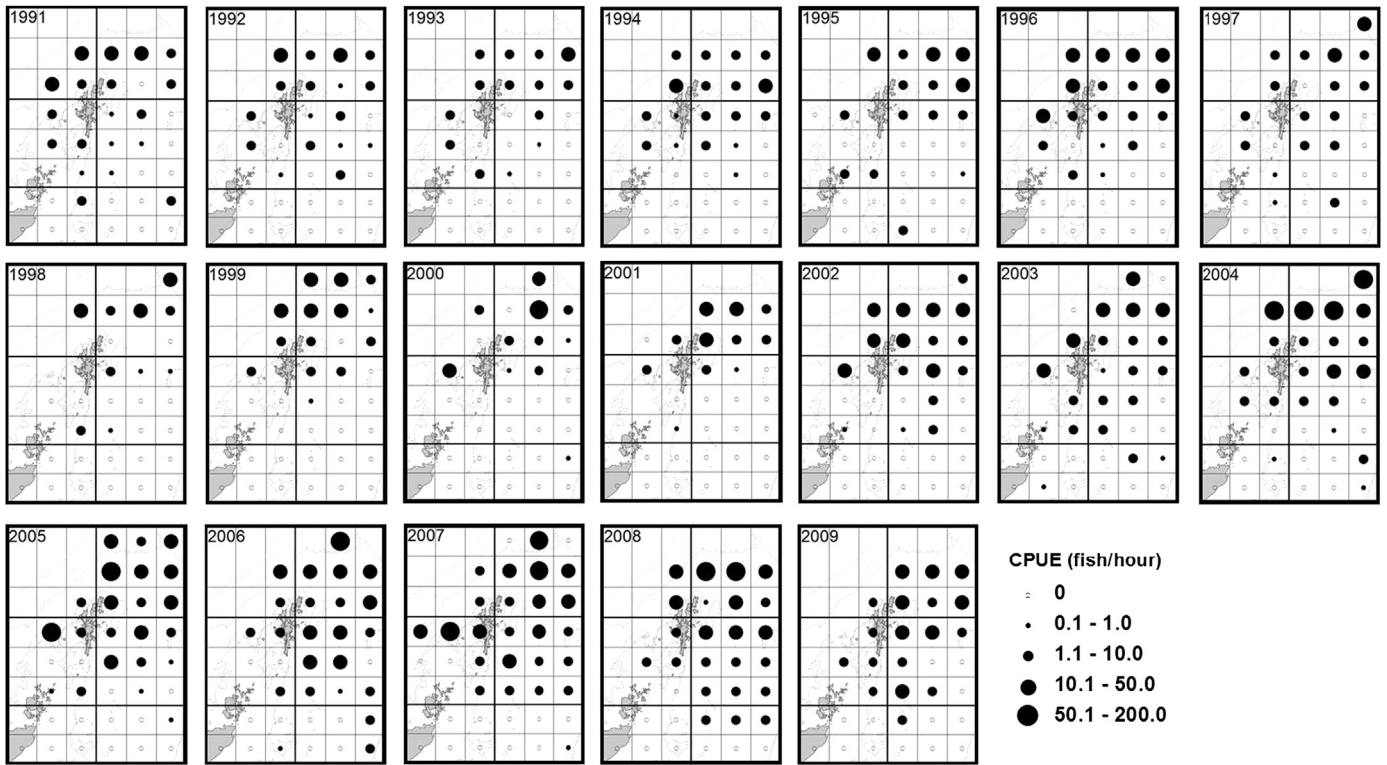
Fig. 6. Distribution and relative abundance of *L. whiffiagonis* in ICES Sub Area IVa from 1991 to 2009.
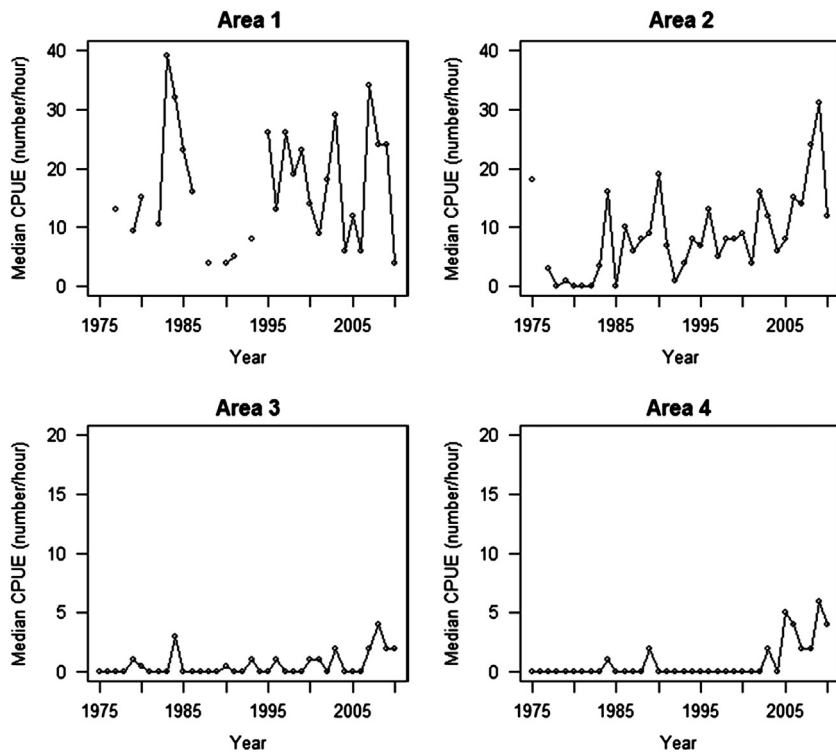*Source*: North Sea International Bottom Trawl Survey (NSIBTS) Quarter 3.

Fig. 7. Median catch per unit effort of megrim from Areas 1–4 of the Q1 survey (NB different *y*-axis scales).

a description of the LPUE rather than the total catch. Discarding of megrim has reportedly been more pronounced in the northern North Sea during the mid-to-late 2000s [21]. As such, there is the potential for the total CPUE to be underestimated in the data presented here due to the absence of any discards from the dataset. However, the issue of discarding has been more pronounced for vessels such as those targeting anglerfish with twin trawls. Megrim has been a species of lesser commercial significance for the sampled vessel here, with catches predominantly incidental. Therefore, the diary data presented here provides a
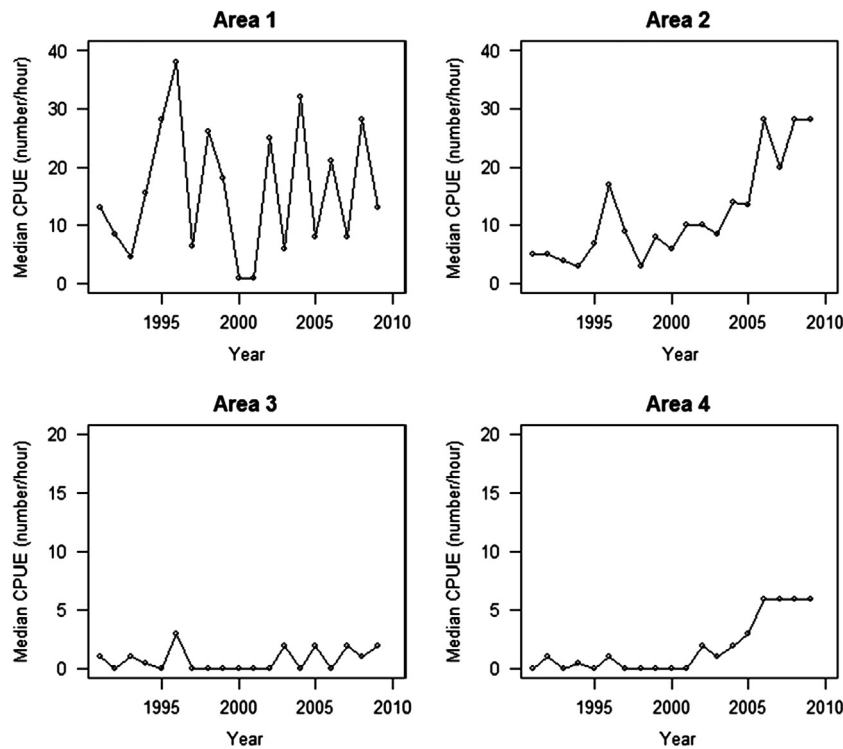
Fig. 8. Median catch per unit effort of megrim from Areas 1–4 of the Q3 survey (NB different *y*-axis scales).

Table 2
Summary of trend co-efficient and associated confidence intervals for models fitted to CPUE data from Areas 1–4 of Q1 and Q3 surveys.

Survey	Area	Model fitted	Trend	Lower 95% CI	Higher 95% CI
Quarter 1	1	ARIMA (0,1,1)	0.016	−0.355	0.388
	2	ARIMA (0,1,1)	0.367[a]	0.167	0.568
	3	Zero-inflated poisson hurdle	0.052	−0.148	0.048
	4	Zero-inflated poisson hurdle	0.761[a]	0.263	1.259
Quarter 3	1	ARIMA (0,1,1)	0.121	−0.787	1.030
	2	ARIMA (0,1,1)	1.310[a]	0.112	2.509
	3	Zero-inflated poisson hurdle	0.023	−0.057	0.104
	4	Zero-inflated poisson hurdle	0.263[a]	0.157	0.369

[a] A significant trend.

useful 'background' overview of trends in abundance over the study period as the vessel was not consistently targeting areas of high megrim abundance.

One of the issues inherent with the use of fishers' historical data is the lack of consistency in the quantity and quality of data collected across vessels. Many of the vessels within the local fishermen's association maintain a regular diary although, for the purposes of this study, only one vessel had the necessary spatial and temporal resolution to estimate catch trends by fishing location on a haul by haul basis. Further, extracting catch data from vessel diaries is time consuming and often references to locally named fishing grounds must be translated on a haul by haul basis to a format consistent with scientific data sources i.e. an ICES statistical rectangle. While fishers may collect long term data sets in a methodical manner, data may not be in a suitable format for collation and analyses. As such, if fishers' catch data is to be considered within a scientific data collection framework, there would be a requirement for it to be collected in a standardised format suitable for scientific analysis. Such attempts have been made at this in the past for both monkfish and megrim by introducing tally book schemes [21,35]. However, one of the problems inherent with these voluntary schemes is the drop-off in participants over time, which can result if fishers' do not see direct benefits from the scheme [36] in terms of utilization of the data and incorporation into the management process.

In recent years modern methods of tracking vessels with vessel monitoring systems (VMS) have allowed for a more streamlined approach to monitoring trends in vessel movement. Currently all European fishing vessels exceeding 15 m are required to transmit vessel position, course and speed for monitoring and enforcement purposes [37]. Vessels are also required to complete daily retained catch weights in logbooks [38]. Routine VMS data can then be linked to catch data to provide spatially resolved catch and effort data [39]. However, the use of VMS is not universal and, where the system is available, historical data is currently limited as it has only been in operation in recent years. Further advances in electronic logbook technology have also resulted in the production of software that allows the user to input biological and ecological data that can be stored and accessed for subsequent analysis (Barkai, personal communication).

A number of novel initiatives between fishermen and scientists have proven to be beneficial. For example, the northern Gulf of St. Lawrence sentinel fishery program enables fishermen to receive training in the collection of data and undertake standardised sampling to collect data on a predetermined range of species [40]. The data collected is relayed to fishermen's association offices and subsequently utilized in assessments on a number of stocks including Atlantic cod (*Gadus morhua*), turbot (*Scophthalmus maximus*) and Atlantic halibut (*Hippoglossus hippoglossus*). However, sentinel surveys could be portrayed as being excessively costly and substantial funding is required to implement them effectively.

Fishers' whole catch data has the potential to inform and improve current assessment methodologies for data poor stocks at a fraction of the cost. The benefits of such data go beyond the ability to provide trends in distribution and abundance and may also provide

opportunities for 'fine tuning' of existing assessments. This is especially true in the case of megrim in Divisions IVa and VIa where fishers' whole catch data, inclusive of discards, has the potential to assist in the current assessment, which presently lacks accurate discard data [22].

If fishers' perceptions and data are consistent with trends of abundance and distribution within scientific data then, due to the time required for scientific data to feed through the assessment process, information from fishers' may act as an early indicator of changes within stocks of fished species. This 'early indication' has been one of the aims of the Fishers' North Sea Stock Survey and agreement exists between fishers' perceptions and survey trends for a number of the species surveyed. The questionnaire also provides fishers' with the opportunity to actively contribute to the assessment and management process for the natural resources they are dependent on.

The results of this study indicate that there is considerable potential for the use of fishers' knowledge and data in the assessment and management process in the demersal fishery in the northern North Sea. To facilitate this, the North Sea Stock Survey, in its current form, could be adapted to include other species of commercial importance, with the resulting species-specific knowledge considered during assessments and benchmarking exercises by appropriate ICES working groups. There is also potential for such a scheme to be expanded to include the utilization of electronic logbooks with the capability of storing biological and ecological data. Furthermore, a standardised approach to the collection and utilization of fishers' data can be achieved if all stakeholders engage in dialog to produce a scientifically robust methodology for the collection of whole catch and distribution and abundance data, consistent with previous tally book schemes. The success of such a scheme would require a formal commitment from all stakeholders to avoid the subsequent drop-off seen in past schemes. An example of one such successful scheme is the Eastern Pacific Ocean skipjack tuna *Katsuwonus pelamis* fishery, where logbook records are mandatory for the international purse-seine tuna fleet [41]. In a recent study, logbook records were used to determine the most productive areas within the fishery as well as long-term spatial and seasonal trends in catches and relative abundance from 1970 to 1995 [41]. Participation in a tally book scheme could be further encouraged by ensuring that the resulting data is utilized in the assessment process and the use of the data is reported back to fishers. Additional incentives have also been recognized as an important element to be considered in the collection of fishery-dependent data [42]. These could be facilitated through the provision of additional effort or quota.

There is a need to ensure that all relevant sources of data are considered if global fisheries are to be assessed and managed robustly and sustainably. The initiatives outlined above have the potential to engage all stakeholders in the production of a robust, structured methodology for collection and utilization of fishers' knowledge and data and also to ensure that necessary feedback exists between stakeholders. An inclusive approach would also serve to instill a greater degree of confidence in the data provided by fishers and its subsequent use within the management process. Further, a structured approach, integrating fishers' knowledge and data, allows for all stakeholders to participate and contribute in the management process and, by ensuring that all available knowledge of a given resource is utilized, provides the most inclusive approach to resource management.

5. Conclusions

The results of this study have shown that trends in the distribution and relative abundance of megrim were broadly comparable between the three data sources, fishers' knowledge, fishers' data and survey data. The utilization of fishers' knowledge and whole catch data, therefore, has the potential to assist in the assessment and management of fish stocks by providing spatially and temporally detailed data on fish distribution and abundance, as well as providing data on key components of assessments such as discards data. A structured approach to fisheries assessment and management requires full transparency and a formal agreement and commitment between all stakeholders to provide and utilize the necessary data required to provide the most effective approach to resource management.

Acknowledgments

References

[1] Anon. State of European fish stocks in 2011. In: European commission seminar, Brussels, Belgium; 8 September 2011.
[2] Berkes F. From community-based resource management to complex systems: the scale issue and marine commons. Ecol Soc 2006;11:45.
[3] Costello C, Ovando D, Hilborn R, Gaines SD, Deschenes O, Lester SE. Status and solutions for the world's unassessed fisheries. Science 2012;338:517–20.
[4] Wilson DC, Raakjær J, Degnbol P. Local ecological knowledge and practical fisheries management in the tropics: a policy brief. Mar Policy 2006;30: 794–801.
[5] Johnson TR, van Densen WLT. Benefits and organisation of cooperative research for fisheries management. ICES J Mar Sci 2007;64:834–40.
[6] Graham N, Grainger R, Karp WA, MacLennan DN, MacMullen P, Nedreaas K. An introduction to the proceedings and a synthesis of the 2010 ICES symposium on fishery-dependent information. ICES J Mar Sci J Cons 2011;68:1593–7.
[7] Drew JA. Use of traditional ecological knowledge in marine conservation. Conserv Biol 2005;19:1286–93.
[8] Johnson TR. Cooperative research and knowledge flow in the marine commons: lessons from the Northeast United States. Int J Commons. North America, 04 November 2009. Available at ⟨http://www.thecommonsjournal. org/index.php/ijc/article/view/110/110⟩ [accessed 16.11.11].
[9] Carr LM, Heyman WD. "It's about seeing what's actually out there": quantifying fishers' ecological knowledge and biases in a small-scale commercial fishery as a path towards co-management. Ocean Coastal Manage 2012;69:118–32.
[10] Maurstad A. Fishing in murky waters—ethics and politics of research on fisher knowledge. Mar Policy 2002;26:159–66.
[11] Foster SJ, Vincent ACJ. Tropical shrimp trawl fisheries: fishers' knowledge of and attitudes about a doomed fishery. Mar Policy 2010;34:437–46.
[12] Zukowski S, Curtis A, Watts RJ. Using fisher local ecological knowledge to improve management: the Murray crayfish in Australia. Fish Res 2011;110:120–7.
[13] Lorance P, Agnarsson S, Damalas D, des Clers S, Figueiredo I, Gil J, et al. Using qualitative and quantitative stakeholder knowledge: examples from European deep-water fisheries. ICES J Mar Sci J Cons 2011;68:1815–24.
[14] Bergmann M, Hinz H, Blyth RE, Kaiser MJ, Rogers SI, Armstrong M. Using knowledge from fishers and fisheries scientists to identify possible groundfish essential fish habitats. Fish Res 2004;66:373–9.
[15] Rochet M-J, Prigent M, Bertrand JA, Carpentier A, Coppin F, Delpech J-P, et al. Ecosystem trends: evidence for agreement between fishers' perceptions and scientific information. ICES J Mar Sci J Cons 2008;65:1057–68.
[16] Nielsen JG. Scophthalmidae. In: Whitehead PJP, Bauchot M-L, Hureau J-C, Nielsen J, Tortonese E, editors. Fishes of the north-eastern Atlantic and the Mediterranean (FNAM). UNESCO, Paris. Berlin: Springer-Verlag; 1989. p. 1286–93.
[17] ICES. Megrim (*Lepidorhombus* spp.) in Divisions IVa and VIa. ICES Advice 2011, The Celtic Sea and West of Scotland; 2011.
[18] ICES. Megrim (*Lepidorhombus* spp.) in ICES Division VIb (Rockall). ICES Advice 2011, The Celtic Sea and West of Scotland; 2011.
[19] Anon. Scottish sea fisheries statistics. Edinburgh: Scottish Government; 2012. p. 1–42.
[20] Fernandes PG. An index of the abundance of megrim on the European northern shelf: 2005–2007. In: Working documents of the working group on the assessment of northern shelf demersal stocks (WGNSDS) 2008: ICES WGNSDS; 2008. p. 38–7.

[21] Laurenson CH, Macdonald P. Collection of fisheries and biological data on megrim in ICES sub-area IVa. Scottish Industry/Science Partnership (SISP) report no 05/082008. p. 44.

[22] ICES. Megrim (*Lepidorhombus* spp.) in Divisions IVa and VIa. ICES Advice 2012, Book 5, The Celtic Sea and West of Scotland; 2012. p. 1–9.

[23] ICES. International bottom trawl survey. ICES ⟨http://datras.ices.dk/Home/Descriptions.aspx⟩ [accessed 15.09.12].

[24] Likert R. A technique for the measurement of attitudes. Arch Psychol 1932;140:52.

[25] Fraser HM, Greenstreet SPR, Piet GJ. Taking account of catchability in groundfish survey trawls: implications for estimating demersal fish biomass. ICES J Mar Sci J Cons 2007;64:1800–19.

[26] Shumway RH, Stoffer DS. Time-series analysis and its applications with R examples. New York: Springer; 2006.

[27] Chan K-S. TSA: time series analysis. R package version 0.98 ⟨http://CRAN.R-project.org/package=TSA⟩ [accessed 22.11.10].

[28] Zeileis A. Econometric computing with HC and HAC covariance matrix estimators. J Stat Software 2004;11:1–17.

[29] Zeileis A. Object-oriented computation of sandwich estimators. J Stat Software 2006;16:1–16.

[30] Cleasby IR, Nakagawa S. Neglected biological patterns in the residuals: a behavioural ecologist's guide to co-operating with heteroscedasticity. Behav Ecol Sociobiol 2011;65:2361–72.

[31] Cryer JD, Chan K-S. Time series analysis with applications in R. 2nd edition. New York: Springer; 2008.

[32] R Development Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, ISBN: 3-900051-07-0 ⟨http://wwwR-projectorg⟩ [accessed 27.06.08].

[33] Gordon JDM. Distribution and biology of anglerfish and megrim in waters to the west of Scotland. European commission – DGXIV, no study contract 98/096; 2001. p. 106.

[34] Begon M, Harper JL, Townsend CR. Ecology: individuals, populations and communities. Oxford: Blackwell Science; 1996.

[35] Dobby H, Allan L, Harding M, Laurenson CH, McLay HA. Improving the quality of information on Scottish anglerfish fisheries: making use of fishers' data. ICES J Mar Sci 2008;65:1334–45.

[36] ICES. Report of the workshop on using fishers to sample catches (WKUFS). ICES CM 2007/ACFM:24; 2007. p. 1–48.

[37] EC. Commission regulation (EC) no. 2244/2003 of 18 December 2003 laying down detailed provisions regarding satellite-based Vessel Monitoring Systems. Off J Eur Union 2003;L 333:17–7.

[38] EEC. Commission regulation (EEC) no 2807/83 of 22 September 1983 laying down detailed rules for recording information on Member States' catches of fish. Off J Eur Union 1983;L 276:1–18.

[39] Gerritsen H, Lordan C. Integrating vessel monitoring systems (VMS) data with daily catch data from logbooks to explore the spatial distribution of catch and effort at high resolution. ICES J Mar Sci 2011;68:245–52.

[40] Gillis DJ. Workshop on the groundfish sentinel program. Ottawa: Department of Fisheries and Oceans, Fisheries Research Branch; 2002. 95.

[41] Trigueros-Salmeron JA, Ortega-Garcia S. Spatial and seasonal variation of relative abundance of the skipjack tuna *Katsuwonus pelamis* (Linnaeus, 1758) in the Eastern Pacific Ocean (EPO) during 1970–1995. Fish Res 2001;49:227–32.

[42] Lordan C, Cuaig MÓ, Graham N, Rihan D. The ups and downs of working with industry to collect fishery-dependent data: the Irish experience. ICES J Mar Sci J Cons 2011;68:1670–8.