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Spatial variation in abundance and catch composition of *Cancer pagurus* in Norwegian waters: biological reasoning and implications for assessment

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The edible crab (*Cancer pagurus*), which is abundant along the Norwegian coast north to Troms County, has been exploited in Norway since the start of the 20th century. The main fishery is in Mid-Norway and Helgeland (63°–67°N), which together land 75% of the Norwegian catch. The fishery is regulated by season, minimum legal size, and the discarding of soft or ovigerous females. Catches have never been systematically described, so this study presents data collected over 4 years by a reference fleet of professional fishers reporting the catch from four standardized trial traps set among their ordinary traps. Catch rate, catch composition, and size distribution from Mid-Norway/Helgeland are compared with the smaller crab fishery in Rogaland (59°N) and with new crab grounds off Vesterålen (69°N). Local variations in size and sex composition between and within region seemed partly to be caused by differences between exposed and sheltered regions, and between heavily and newly exploited grounds. Size distribution is used as an indicator to determine a suitable sampling strategy. The most efficient survey design is seemingly the collection of relatively small samples from many boats to reduce the between-vessel component of variation. A suggested strategy to obtain an abundance index would be to collect daily catch rates from all commercial landings.

Keywords: abundance index, *Cancer pagurus*, catch rates, management, size distribution.

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Introduction

The edible crab *Cancer pagurus* is abundant along the Norwegian coast up to Troms County, and an increasing bycatch of the species in gillnets indicates that the resource is spreading northwards. Crab landings increased during the past decade from 1732 t in 1994 to 5236 t in 2004. At present the main crab fishery takes place in shallow water from the outer skerries, situated from 10 to 25 nautical miles from the coastline, to the fjords. In Mid-Norway and Helgeland (63°–67°N) the peak season is from August to November. Some 75% of the Norwegian landings of edible crab are from those regions, and nearly 90% of the landings go to processing factories, the biggest with a recent annual turnover of 2000–2500 t. Both interest and effort in the fishery are growing.

In Mid-Norway and Helgeland the crab has been exploited since the 1940s. However, the fishery decreased in the 1970s and no exploitation took place out of Helgeland in the 1980s. The fishery then reopened in 1997 with an increasing number of fishers and enhanced annual landings. In Mid-Norway the fishery continued in the 1980s with annual landings around 900 t, but in the past decade landings have tripled.

Important regional crab fisheries extend south of Mid-Norway, although on smaller scales. In Rogaland (59°–60°N) the fishing season is between April and November. There, coastal crabs have been utilized for approximately 100 years, and they support local live sale markets and industry. In Vesterålen (69°N), the crab fishery started in 2001, and it is currently prosecuted from October to November. It is negatively impacted by inclement (rough or cold) weather, as well as by the need for long transport to processing plants to the south. Few fishers participate.

No systematic description of the population structure or abundance of the crab stock in Norwegian waters exists, except for total landings. Both effort and biological information are missing. In addition to defined seasons, the fishery has been regulated by a ban on the landing of soft-shelled and ovigerous crabs, as well as through a minimum legal size (MLS). The present MLS is 13 cm carapace width (CW) north of 60°N, though it was 11 cm CW in the south in the 1950s. The difference then was based on a subjective opinion that the crabs were in general smaller in the southern regions.

Large crab fisheries in the UK and France have existed for more than 30 years, and have stimulated studies of various aspects of crab life history: reproductive cycle, growth, movement, catchability, and population structure. All these factors influence the crab fishery and stock management. Several approaches are undertaken to assess long-lived crustacean stocks. A main objective for the assessments is to predict the short- and long-term gains and losses in landings from changes in the MLS. The estimation of mortality parameters through the use of age-based models is impossible, because age determination of decapod crustaceans is difficult and time-consuming (Sheehy *et al.*, 1996, 1999). The common approach for the crab has therefore been length-based yield-per-recruit analyses (Bennett, 1979) and length cohort analysis (Addison and Bennett, 1992). Both methods are sensitive to input parameter estimates for natural mortality and growth rate. They assume that size distribution data aggregated on a wide geographic scale are representative of the biological structure in the stock. However, there are doubts about these assumptions, because females undertake extensive migrations thought to be related to the reproductive cycle (Edwards, 1979; Bennett and Brown, 1983; Latrouite and Le Foll, 1989). Additionally, catchability is influenced by size, sex, moult condition, and environmental conditions (Hancock, 1965; Bennett, 1995). Collecting size distribution data at a suitable spatial and temporal scale is therefore crucial to effective stock assessment based on these methods (Tully *et al.*, 2002). Data sampling through compulsory completion of fishing logbooks allows the collection of more biological data as well as information on yield per effort. Starr and Vignaux (1997) compared a logbook programme based on detailed information from a limited number of traps with data from more traditional surveys. Their programme for the New Zealand rock lobster fishery showed better correlation with the data from the catch reporting system than the traditional survey data.

Owing to a lack of abundance data and biological stock parameters in Norway it has been impossible to advise either industry or decision-makers on how to develop further the crab fishery beyond present catch levels. However, a strong call from the Norwegian industry initiated a resource programme, based on registration from fishers as a reference fleet (Starr and Vignaux, 1997). The results presented here are derived from part of that programme, which commenced in 2001 (Anon., 2003; Woll *et al.*, 2003). The fishery in Mid-Norway and Helgeland is compared with the smaller fishery in Rogaland and the new trial fishery in Vesterålen. We use the regional data on spatial variation in catch rates, biological stock parameters, and theories of sampling design and efficiency to discuss some implications for assessment and management of the edible crab off Norway.

Material and methods

Geographical distribution

The reference fleet was selected on the basis of individual fisher experience and geographical distribution. Although coastal Norwegian fisheries are designated by ICES statistical rectangle, such areas do not fit the local crab fisheries. The reference fleet was therefore grouped on the basis of the regions of the different fish sales organizations (Figure 1). The number of fishers participating within each region is based on the level of effort of the fishery in that region. (i) Mid-Norway (62°–65°N): 13 fishers

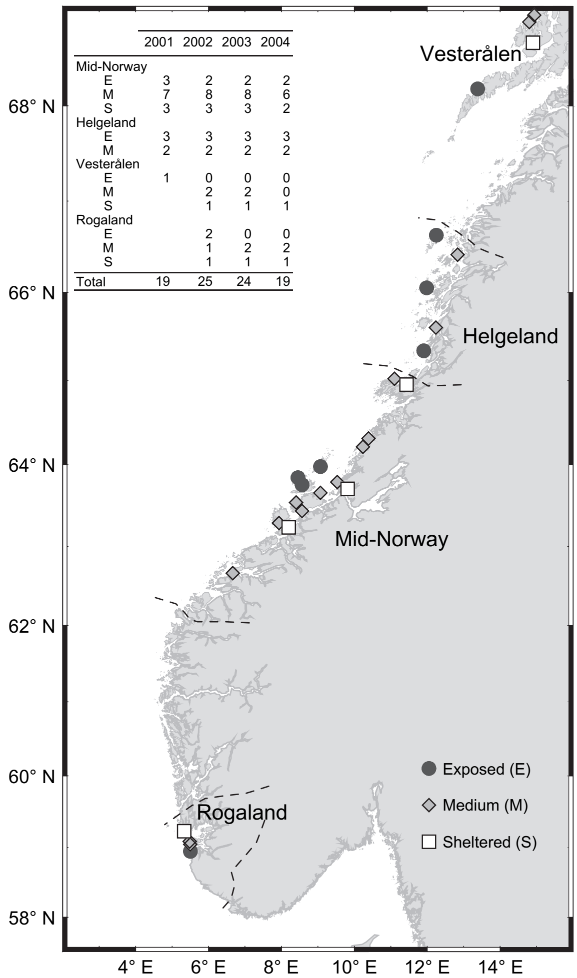

Figure 1. Locations of operations of the fishers from 2001 to 2004, described per region and exposure category. The tabulation shows the number of fishers (boats) and their location.

(10 in 2004), (ii) Helgeland (65°–67°N): five fishers, (iii) Rogaland (58°30′–59°30′N): three fishers (none in 2001), and (iv)Vesterålen (68°30′–69°N): three fishers (one in 2001 and 2004).

The crab fishery is conducted in shallow water from the outer exposed skerries, situated from 10 to 25 nautical miles from the coastline, to more sheltered fishing grounds in the fjords and to leeward of the larger islands. Exposure can be evaluated using the formula of Oug *et al.* (1985), which predicts the extent of exposure on the basis of the sum of the distance from land, and the direction and frequency of the wind on each of three different scales: local, fjord, and ocean. The method gives a good description for a small locality. However, each fisher, even if he fishes in a limited area, spreads his traps out in places with different local scales of exposure. The full formula was therefore not used in this study, but exposure was evaluated on a larger scale, the outer skerries being considered as exposed (ocean) and the fjords and protected grounds leeward of large islands as sheltered. The level of exposure was classified as medium when traps were distributed in places of intermediate exposure or when they were set in several exposure levels. Only the Mid-Norway region had fishers in exposed and sheltered categories, so this region was used to give an indication of between-exposure difference (Figure 1).

Data collection

From 2001 to 2003, relatively large amounts of information were collected to allow for detailed description. Each fisher collected samples from 10 weeks of the season, making four reports weekly (Table 1). The data made it possible to calculate if and how much the registration programme could be simplified without losing precision. Following from this initial evaluation, therefore, sampling in 2004 was reduced to 5 weeks, with fishers making two weekly reports. The sampling period was then one month (September; but October for Vesterålen; Table 1).

The standardized trial traps of the project were moulded black polyethylene, measuring 80 cm × 35 cm around and 31 cm high, with entrances on each short side of the trap.

All crabs from the trial traps were recorded in each report: CW to the nearest ½ cm, sex, soft/pale (to be discarded), ovigerous females (discarded), other discards. Each report also included the total number of traps hauled, the landings (kg; based on the total numbers of traps hauled), the soak time (number of days), the bait, and the fishing depth.

Catch rates

The daily catch rate for all traps per fisher was calculated from the landings as: lpue (all traps) = landings in kg per total number of trap hauls. The daily catch rates for the trial traps were calculated in terms of both number and

Table 1. Number of daily reports and crabs measured, and the sampling period. From 2001 to 2003 each boat collected data from 10 weeks in the season (four daily reports each week), and in 2004 from 5 weeks (two daily reports each week).

Region	Number of daily reports*				Number of crabs recorded				Sampling period			
	2001	2002	2003	2004	2001	2002	2003	2004	2001	2002	2003	2004
Mid-Norway	478	496	451	100	13 410	16 743	15 976	3 991	August–November	August–November	July–November	September
Helgeland	240	187	179	52	6 928	6 134	5 426	1 738	August–November	August–November	August–November	September
Vesterålen	19	61	95	10	276	896	1 030	227	October–November	October–November	October–November	October
Rogaland		141	99	30		6 058	4 595	1 919	–	August–October	May–October	September
Sum	737	885	824	192	20 614	29 831	27 027	7 875				

*Each report mainly from four standardized trial traps.

weight (kg) of crabs: cpue (trial traps) = number (or kg) of crabs per trial trap haul. For more than 1 day's soak time, the catch rate was standardized to 1-day soak time (see Results).

For trial traps the following catch rates were determined: landed crabs (lpue), discards (dpue), and total catch (cpue = lpue + dpue). Discard catch rates were further divided into those for crabs smaller than the MLS (13 cm CW for Mid-Norway, Helgeland, and Vesterålen; 11 cm for Rogaland), soft or pale crabs, ovigerous females, and other discards, e.g. crabs with severe black spot disease and crabs without claws.

Additional to the trial traps, the weight (g) of the crabs was estimated on the basis of the relationship between CW and live weight (W). For crabs of CW $\geq$13 cm, the weights of females and males were estimated separately (AKW, unpublished). For crabs of CW <13 cm, a relationship for both sexes was used (R. Martinson, unpublished). These relationships are:

Females $\geq$13 cm CW: $W = 0.000243\text{CW}^{2.9026}$ ($n = 301$; $r^2 = 0.958$);
Males $\geq$13 cm CW: $W = 0.000023\text{CW}^{3.4115}$ ($n = 78$; $r^2 = 0.923$);
Both sexes <13 cm CW: $W = 0.000097\text{CW}^{3.1236}$ ($n = 314$; $r^2 = 0.982$).

For comparisons between the lpue in all traps and in the trial traps, data from the initial 10-week sampling period were used. The trial trap data were used to compare catch rates and biological data between and within regions. In order to eliminate the effect of season, 5 weeks covering September for Mid-Norway, Helgeland, and Rogaland, and October for Vesterålen, were used for the purpose.

Size and sex distribution

For crabs landed, between-region, year, and sex differences in mean and maximum CW were evaluated, as well as the frequency of females. Size and sex distribution for the total catch was calculated by 1 cm CW interval, and between-region and year differences were analysed. For exposed and sheltered grounds in the Mid-Norway region, differences in size and sex distribution were evaluated.

Statistical analyses and sampling theories

When testing differences in catch rates, the data were log-transformed to obtain a normal distribution. ANOVA was used to test differences in overall lpue (for all traps, and for trial traps) for the different regions. For trial traps, ANOVA was also used to test between-region, year, and exposure categories in the catch rate data (Model: Log(CATCH RATE + 1) = REGION + YEAR + EXPOSURE). ANOVA was further used to test between-year differences for the four regions, and between-exposure category for the Mid-Norway region. Bonferroni statistics indicated which groups differed from each other. Significance level was set at 95%. ANOVA was also used to test mean CW between-region, year, and exposure category for landed female and male crabs. Significance level was set to 99.5% in those tests owing to the large number of measurements. SYSTAT v. 10.2 was used in all analyses.

An initial analysis describing the main sources of sampling variance was carried out. This was used to indicate how well the sampling scheme described biological population parameters within the different regions. The analysis may form the basis for later changes to the sampling scheme, but are also helpful in terms of evaluating the results from the present study. The analysis followed Helle and Pennington (2004), and data collected in 2003 formed the basis for the analyses. Mean CW was used as an indicator of biological population parameters in the analysis.

The method, which includes a variance component analysis (see Helle and Pennington, 2004, and references therein), gives an indication of the relative importance of the different sources of variance to the estimated mean CW in the data. To evaluate various sampling schemes, the estimates of the different variance components were substituted into an equation for the variance of the estimator of mean length $\hat{\mu}$ (equation 3 of Helle and Pennington, 2004):

$$\text{Var}(\hat{\mu}) = (1 - f_f)\frac{\sigma_f^2}{n} + (1 - f_w)\frac{\sigma_\text{w}^2}{nm} + \frac{\sigma_\text{e}^2}{nml}, \qquad (1)$$

where f_f is the proportion of fishers involved in sampling and f_w is the proportion of available weeks sampled. The parameters n, m, and l represent the expected total number of fishers, the average number of weeks fished per fisher, and the average number of crabs measured per week per fisher, respectively. This allows for an indication of how the standard error of the mean length would be expected to change with a varying number of fishers, number of sampling weeks, or number of crabs measured.

Results

In September, the crab fishery of Mid-Norway, Helgeland, and Rogaland was mainly at depths of 20−30 m, shallower during summer and successively deeper from October, down to 40−50 m in November. It is concluded that fishing depth would not have caused any inter-regional differences.

Saithe, pieces of saithe, and other gadoids were the preferred bait in 85% of the reports received, mackerel, herring, dogfish, salmon, and redfish being used just occasionally. The data do not allow for an analysis of how bait may have influenced the catches.

In all, some 85 000 crabs were measured in the four regions (Table 1). Catch rates from trial traps were calculated from approximately 10 000 trap hauls in 2600 daily reports. A soak time of 1 or 2 days was reported from 54% and

35% of the daily reports, respectively. Three or more than 3 days' soak time were sporadic occurrences, just 8% and 3% of the reports, respectively. The catch rate varied with soak time (ANOVA: $F_{3,\ 2625} = 14.097$, $p < 0.001$), but not between regions. Catch rates for 1-day soak time were significantly lower than for 2 days' soak time (Bonferroni: $p < 0.001$) and 3 days' soak time (Bonferroni; $p = 0.002$), but not different for >3 days' soak time. The difference was not significant between 2 and 3 days' soak time. Catch rates for 2 and 3 days' soak time were on average 12.7% higher than catch rates for a 1-day soak time. For comparative purposes hereafter, catch rates were adjusted accordingly to correspond to a 1-day soak time.

Catch rates and catch composition

The efficiency of the trial traps was evaluated by comparing the lpue of trial traps with that of all traps (as kg per trap haul). Only non-systematic deviations were present in the accumulated data sets from Mid-Norway ($F_{1,\ 3039} = 0.002$; $p = 0.963$), Helgeland ($F_{1,\ 1314} = 0.332$; $p = 0.564$), and Vesterålen ($F_{1,\ 357} = 1.872$; $p = 0.172$). For Rogaland, however, there were differences ($F_{1,\ 537} = 13.481$; $p < 0.001$). This was probably partly due to the sampling procedure. Crabs smaller than the MLS in the trial traps were enumerated by measuring them, but in the all traps category, judgement of the fisher was invoked. For Rogaland this resulted in the discard of several crabs greater than the MLS of 11 cm, though not for the other regions where the MLS was 13 cm (pers. obs.). Catch rates based on landings from all traps were fairly stable, probably because of the large number of traps (approximately 200 vs. four daily trial traps). However, they were not standardized and did not provide biological data as did the trial traps. Data from the trial traps are therefore used subsequently for analysis.

ANOVA showed that region had a significant effect on overall lpue (kg per trap haul; $F_{3,\ 1495} = 186.44$; $p < 0.001$), but the effects of year ($F_{1,\ 1495} = 4.97$; $p = 0.026$) and exposure ($F_{1,\ 1495} = 6.91$; $p = 0.009$) were not significant.

Comparing the accumulated mean lpue for the years 2001−2004 between regions (Table 2), lpue was highest for Helgeland (3.4), followed by Mid-Norway (2.7), Rogaland (2.0), and Vesterålen (1.3). There were no differences in the overall mean lpue per exposure category in Mid-Norway (ANOVA; $F_{2,\ 833} = 1.548$; $p = 0.213$; Table 2). To allow comparison between Rogaland and the other regions, lpue for the former was calculated allowing for the MLS to be 13 cm CW, i.e. the lpue was smaller (1.5) than in reality given the smaller MLS there.

Mean lpue varied between years (Figure 2). For Mid-Norway lpue was higher in 2002 and 2004 than in 2001 and 2003 ($F_{3,\ 833} = 9.588$, $p < 0.001$). In Helgeland lpue was highest in 2001 and 2002, decreasing in 2003 and levelling out in 2004 ($F_{3,\ 64} = 5.751$, $p = 0.001$; Bonferroni: $p = 0.004$). In Vesterålen lpue was stable from 2001 to 2003, then increased in 2004 ($F_{3,\ 181} = 8.173$, $p < 0.001$; Bonferroni; $p < 0.001$). For Rogaland, lpue was lowest in 2002, increased in 2003, and levelled out in 2004 ($F_{2,\ 117} = 19.992$; $p < 0.001$; Bonferroni; $p < 0.001$). The differences found between years are indicative of data with no trend. In Vesterålen and Rogaland the differences are believed to have been caused as a result of few fishers participating and some change in the preferred fishing grounds between years.

For overall mean cpue (number of crabs per trap haul), ANOVA revealed significant effects for region ($F_{3,\ 1495} = 236.71$; $p < 0.001$), year ($F_{1,\ 1495} = 49.09$; $p < 0.001$), and exposure ($F_{1,\ 1495} = 218.38$; $p < 0.001$). Between-region

Table 2. Mean catch rates for September (October for Vesterålen) in the years 2001−2004 (mean ± s.e.)*. Cpue from total catch; lpue from landed catch; dpue from discards; *n* is the number of daily reports.

		Catch rate (kg per trap haul)	Number of crabs per trap haul				
					dpue		
Area	*n*	lpue	cpue	lpue	Soft > MLS	Others > MLS	<MLS
Mid-Norway	833	2.7 ± 0.04^b	8.6 ± 0.13^b	5.0 ± 0.08^b	1.3 ± 0.04^b	0.1 ± 0.01^b	2.2 ± 0.07^b
Helgeland	364	3.4 ± 0.07^a	7.6 ± 0.20^c	6.2 ± 0.15^a	0.4 ± 0.05^c	0.4 ± 0.03^a	0.6 ± 0.05^c
Vesterålen	181	1.3 ± 0.05^d	3.6 ± 0.14^d	2.5 ± 0.10^c	0.4 ± 0.04^c	0.2 ± 0.02^b	0.5 ± 0.07^c
Rogaland	117	2.0 ± 0.08^c	13.4 ± 0.55^a	5.3 ± 0.23^b	5.0 ± 0.31^a	0.2 ± 0.04^b	2.9 ± 0.32^a
p-values		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mid-Norway							
Exposed	151	2.8 ± 0.08	9.6 ± 0.25^a	4.3 ± 0.13^b	1.6 ± 0.07^a	0.1 ± 0.03^b	3.7 ± 0.18^a
Medium	481	2.7 ± 0.05	9.2 ± 0.17^a	5.3 ± 0.10^a	1.5 ± 0.06^b	0.2 ± 0.01^a	2.3 ± 0.08^b
Sheltered	201	2.6 ± 0.08	6.4 ± 0.26^b	4.8 ± 0.17^b	0.6 ± 0.05^c	0.1 ± 0.02^b	1.0 ± 0.10^c
p-values		0.213	<0.001	<0.001	<0.001	<0.001	<0.001

*Catch rates with different superscript letters within a column are significantly different.

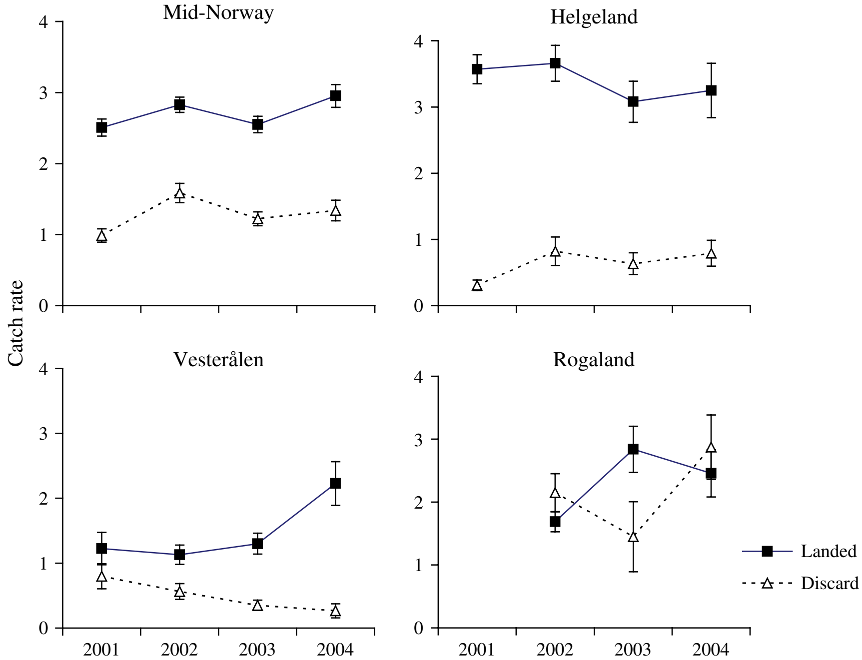

Figure 2. Catch rates (kg per trial trap haul, mean ± 95% C.I.) for landed and discarded crabs in September (October for Vesterålen), by region and year. The minimum legal size for Rogaland is 11 cm CW, for the other regions 13 cm.

differences ($F_{3,\ 1495} = 205.2$; $p < 0.001$) were particularly pronounced for Rogaland, where the number of crabs per trap haul was about double that of Mid-Norway and Helgeland (Table 2). Differences in cpue between exposure category for Mid-Norway were also apparent, being higher in exposed than in sheltered grounds (ANOVA; $F_{2,\ 833} = 98.348$; $p < 0.001$; Bonferroni; $p < 0.001$). This was partly due to the greater prevalence of crabs <MLS on the exposed grounds (Table 2).

Between-year variations were found for Mid-Norway. Cpue was lowest in 2001 and highest in 2004 ($F_{3,\ 833} = 22.31$; $p < 0.001$; Bonferroni; $p < 0.001$); there were no differences between 2002 and 2003. Analysis of the catches showed that the variation was partly attributable to the proportion of crabs smaller than the MLS increasing from 20% in 2001 to 35% in 2004 (Figure 3). Between-year differences in cpue were not found for Helgeland, but the frequency with which crabs smaller than the MLS were captured there also rose between 2001 and 2004, from 7% in 2001 to 12% in 2004 (Figure 3). In Vesterålen and Rogaland between-year differences in cpue were found (Table 2), but there was no trend in the frequency with which crabs smaller than the MLS were caught (Figure 3).

Sex ratio and size of landed crabs

Most of the landed crabs in Mid-Norway, Helgeland, and Vesterålen were females, 74%, 79%, and 84% on average, respectively, for 2001–2004. For Rogaland the sex ratio was closer to unity (54% females; Table 3). In Mid-Norway and Helgeland the proportion of females decreased during the sampling period, in Mid-Norway from 77% in 2001 to 67% in 2004, and in Helgeland from 86% to 73% for the same years. This trend was not apparent for either Rogaland or Vesterålen (Table 3).

ANOVA showed significant effects on overall female CW for each region ($F_{3,\ 21\,870} = 988.45$; $p < 0.001$), and exposure category ($F_{1,\ 21\,870} = 575.15$; $p < 0.001$), but not for year ($F_{1,\ 21\,870} = 8.04$; $p = 0.005$). For male CW the effects were significant for region ($F_{1,\ 7613} = 383.67$; $p < 0.001$), year ($F_{1,\ 7613} = 51.85$; $p < 0.001$), and exposure ($F_{1,\ 7613} = 8.14$; $p = 0.004$).

Overall mean CW of landed females was different in all regions ($F_{3,\ 21\,870} = 808.33$; $p < 0.001$; Table 3), greatest for Helgeland (15.2 cm), then Vesterålen (14.9), Mid-Norway (14.8), and Rogaland (13.4). For landed males, CW was largest for Mid-Norway (15.2 cm), smallest for Rogaland (13.2), and there was no significant difference between Helgeland (14.9) and Vesterålen (15.0; Table 3). If calculated according to an MLS of 13 cm, the mean CW in Rogaland would have been 14.1 cm (females) and 14.4 cm (males), still smaller than in the other regions. Annual changes within region were notable for males in Mid-Norway, which were much smaller in 2004 than in the earlier years (Table 3).

Size and sex distribution

Size distribution was different by gender. For crabs smaller than the MLS, females and males were in approximately equal number. For Mid-Norway, Helgeland, and Vesterålen

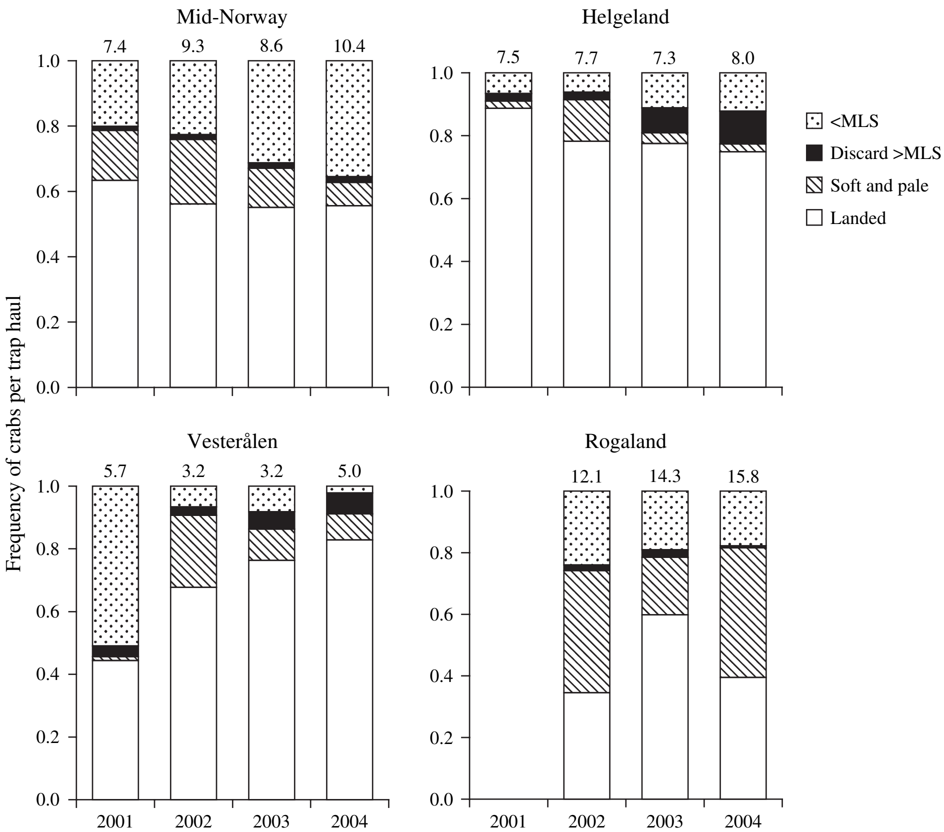

Figure 3. Proportional catch composition of edible crab categories in September (October for Vesterålen), by region and year. The average number of crabs per trap haul is indicated above each histogram. The minimum legal size for Rogaland is 11 cm CW, for the other regions 13 cm.

females larger than the MLS were numerically dominant to males of similar size, whereas in Rogaland the distribution was more even. In Mid-Norway, Helgeland, and Vesterålen, most females were between 14 and 16 cm CW, slightly smaller for Mid-Norway then for Helgeland. In Rogaland most females were between 13 and 14 cm CW. In Vesterålen there was a double peak in size distribution in 2001, different from the situation subsequently, when the distribution was similar to that of Mid-Norway and Helgeland (Figure 4).

Differences in size and sex distribution attributable to exposure were apparent in Mid-Norway. Most females caught in the sheltered region were 14−16 cm CW, whereas those caught in exposed regions were evenly distributed across the size spectra (Figure 5). The overall proportions of females were 78.5% and 46.4% for sheltered and exposed grounds, respectively. Overall, 14.7% of the crabs collected in sheltered grounds and 38.4% of those collected in exposed areas were below the MLS.

Sampling scheme

Analyses of the data for all regions showed that the variation component caused by the sample size (within-variation component) was small compared with the total variation. The largest source of variability by far was in the boat component (Table 4). Reducing the sample size or the number of weeks each fisher sampled would not reduce the variance in mean CW markedly (Table 4; Figure 6).

Discussion

The data collected were sufficient to evaluate the classic assessment information on abundance and catch composition in terms of sex ratio, size distribution, and quality in the form of marketable or discard material through being ovigerous, soft, damaged, or smaller than the MLS. Catch composition differences can be caused by the use of different types of gears (Addison and Lowell, 1991), or different soak times (Bennett, 1974; Fogarty and Addison, 1997). The study provided fishers with standardized trial traps to be placed between their standard traps, to preclude bias attributable to gear differences. Fishing depth varied between months, but because such differences were similar in all regions, this factor was not important when comparing catches from the same period.

The data did reveal variations in catch rates and catch composition both between regions and fishing ground

Table 3. Sex ratio and carapace width (CW, cm; mean ± s.d.)* for edible crab landed in September (October for Vesterålen), separated by region and year. Minimum legal size for Rogaland is 11 cm CW, for the other regions 13 cm.

Area and parameter	2001	2002	2003	2004	*p*-values	Mean, 2001–2004
Mid-Norway						
n	4 713	4 909	4 280	2 104		16 006
% Female	77.1	73.0	73.4	66.5		73.5
CW female (mean)	14.7 ± 1.3^{b}	14.8 ± 1.3^{a}	14.8 ± 1.3^{ab}	14.6 ± 1.3^{c}	<0.001	14.8 ± 1.3
CW female (maximum)	20.0	21.0	22.5	19.0		22.5
CW male (mean)	15.5 ± 2.0^{a}	15.3 ± 1.9^{ab}	15.2 ± 2.0^{b}	14.7 ± 1.7^{c}	<0.001	15.2 ± 1.9
CW male (maximum)	24.0	26.5	26.0	22.0		26.5
Helgeland						
n	3 575	2 408	2 094	1 255		9 332
% Female	85.5	74.5	77.7	72.6		79.2
CW female (mean)	15.1 ± 1.4^{c}	15.5 ± 1.3^{a}	15.2 ± 1.4^{b}	15.1 ± 1.3^{bc}	<0.001	15.2 ± 1.4
CW female (maximum)	21.0	19.5	20.0	19.0		21
CW male (mean)	14.6 ± 1.3^{b}	15.5 ± 1.3^{a}	14.6 ± 1.4^{b}	14.7 ± 1.4^{b}	<0.001	14.9 ± 1.4
CW male (maximum)	19.5	20.0	19.0	21.0		21
Vesterålen						
n	122	516	791	188		1 617
% Female	81.1	83.1	84.5	88.8		84.3
CW female (mean)	14.6 ± 1.2	14.9 ± 1.3	15.0 ± 1.3	15.0 ± 1.1	0.053	14.9 ± 1.3
Cw female (maximum)	19.0	19.0	20.0	18.0		20
CW male (mean)	13.9 ± 0.7^{b}	14.6 ± 1.1^{b}	15.4 ± 1.5^{a}	15.5 ± 1.3^{a}	<0.001	15 ± 1.4
CW male (maximum)	15.0	17.5	19.0	17.5		19
Rogaland						
n		1 206	566	756		2 528
% Female		55.6	48.9	54.4		53.7
CW female (mean)		13.6 ± 1.5^{a}	13.0 ± 1.3^{b}	13.2 ± 1.2^{b}	<0.001	13.4 ± 1.4
CW female (maximum)		18.0	18.0	17.0		18
CW male (mean)		13.4 ± 1.6^{a}	12.5 ± 1.3^{b}	13.3 ± 2.1^{a}	<0.001	13.2 ± 1.7
CW male (maximum)		18.5	18.0	19.5		19.5

*Annual mean CW values with different superscript letters within a row are significantly different.

exposure category. As fishing was conducted by a limited number of boats, each trapping in a limited region, there is a risk of introducing positive intra-cluster correlation (Pennington *et al.*, 2002), meaning that the catch composition would tend to be rather more uniformly similar than would be the case in the entire population, e.g. gender, size, and stomach contents. This is often a problem with crab and lobster fisheries and can lead to unreliable assessment (Miller, 1990; Addison and Lowell, 1991). Because we recognize that such problems could exist in the data presented here, we start by discussing abundance and catch composition, then follow with a discussion of the precision of the data, and the impact the results might have on assessment and management regimes, based on the Helle and Pennington approach (2004).

Abundance, catch composition, sex ratio, and size distribution

As an index of abundance, catch rates, expressed here as kg per trap haul (lpue), are often used even if they are not representative of the entire population. Even if cpue or lpue are not reliable indices, some index of abundance is still needed in order to conduct an assessment. Lpue is often the best or only available index, and is therefore often used (Addison, 1997), making it crucial that soak time at least be made consistent, if possible (Fogarty and Addison, 1997). Therefore, here we standardized all data to 1-day soak time, to produce comparable data for the statistical calculations. In this way, the mean abundance calculated for September of the years 2001–2004 was highest for Helgeland (3.4 kg per trap haul), then Mid-Norway (2.7), Rogaland (2.0), and Vesterålen (1.3). There was no trend between years.

The mean lpue in Norway is higher (>2 kg per trap haul) than off Ireland, the UK, or France (<2 kg per trap haul; Tully *et al.*, 2002; Anon., 2003, 2004). However, unlike in other countries, Norwegian catch rates are based on data collected in a single month only (September), at the peak of the season, whereafter they decrease (Woll *et al.*, 2003). In around-year fisheries, catch rates of edible crab tend to be best in summer and autumn (Tully *et al.*,

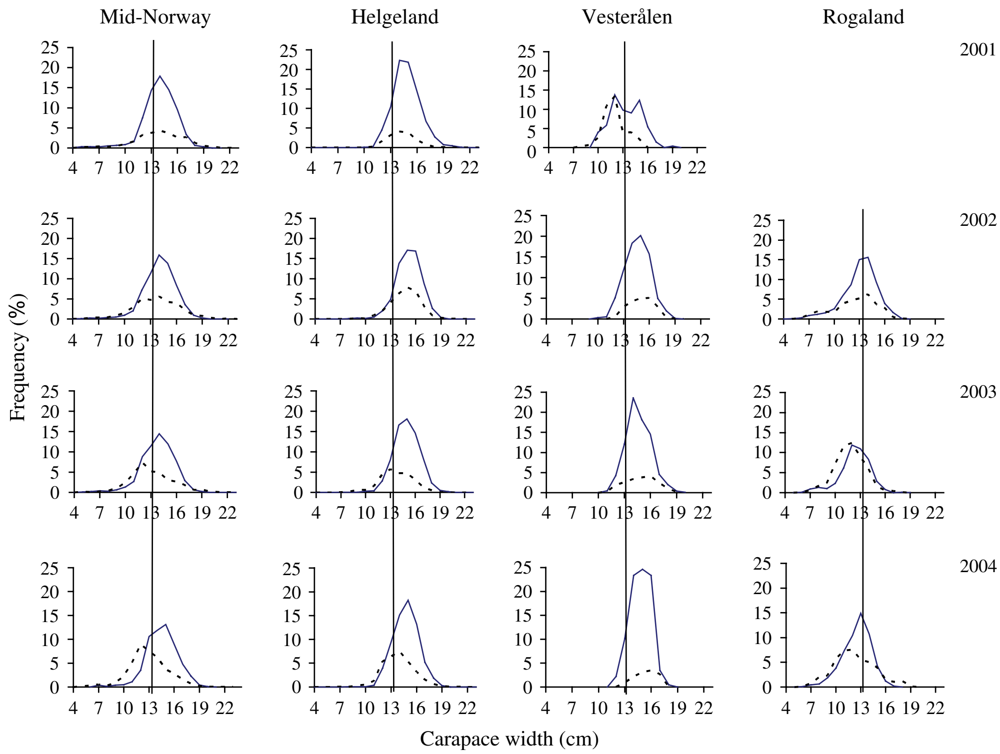

Figure 4. Size distribution of crabs collected in September (October for Vesterålen), by region and year, for females (unbroken line), and males (dashed line) separately. The vertical line is the MLS by CW, except for Vesterålen, where it is actually 11 cm but the 13 cm MLS line is shown for comparison.

2002), owing to migration and the aggregation of adult females in certain regions (Edwards, 1979, 1989; Brown and Bennett, 1980). Direct comparison of the catch rate data between countries is therefore difficult.

The rate of exploitation is another factor that can influence catch rates and catch composition. In Mid-Norway the crab fishery has been continuous since the 1950s. In Helgeland the crab fishery reopened in the late 1990s after a 10-year pause, so the better catch rates there may be due to that period of reduced exploitation. Increased effort associated with a decrease in lpue has been reported from Ireland (Anon., 2003, 2004). Based on the official statistics for landings and the number of participating fishers, effort in the crab fishery off Mid-Norway and Helgeland has increased over the past 4−5 years. The results given here indicate an increase in the frequency of crabs smaller than the MLS and a decrease in the annual mean CW of crabs landed during the experimental period. The increase in number of smaller crabs may be a consequence of good recruitment, but traps are selective and smaller crabs tend to avoid entering traps when bigger crabs are already inside. The increase in number of smaller crabs may therefore just as likely be the result of there being fewer large crabs on the ground, allowing more smaller crabs to enter

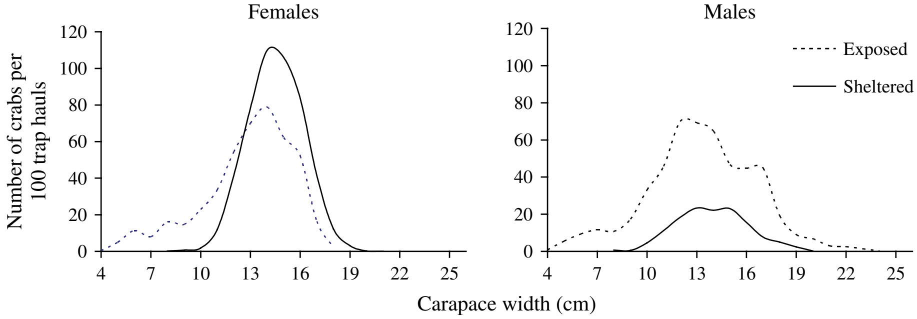

Figure 5. Size distribution of female and male edible crabs per 100 trap hauls in exposed and sheltered regions in Mid-Norway. Crabs were collected in September of the years 2001−2004.

Table 4. Contribution of each component of the variance to the total variance for all data collected during 10 weeks in 2003 in Mid-Norway, Helgeland, Vesterålen, and Rogaland. The numbers of crab fishing boats and weeks in a season for each region are given in parenthesis.

	Sampling scheme				Sources of variance			Overall mean	
Area	Fishers (f)	Weeks (w)	Crabs measured per week (l)	Number of crabs measured	Fisher component	Day component	Within component	Variance	s.e.
Mid-Norway	13 (201)	10 (18)	123	15 976	63.520	0.101	0.0003	63.621	7.976
Helgeland	5 (50)	10 (15)	109	5 426	81.507	0.066	0.0004	81.573	9.032
Vesterålen	3 (6)	10 (12)	34	1 030	3.271	0.017	0.0018	3.290	1.814
Rogaland	4 (50)	10 (30)	115	4 595	118.015	0.464	0.0008	118.479	10.885

the traps. The lesser frequency of female crabs in 2004 may be due to the fishery having exploited females then. However, it may also be due to market conditions; owing to an enhanced value of big claws, demand for male crabs increased. Such market trends tend to influence the fishers' way of setting traps by depth and substratum type, in an attempt to increase the catch of male crabs.

In Vesterålen the fishery has been of an experimental character, so the fishers sometimes collect data from unfavourable grounds. The lpue is therefore not directly comparable with that of other regions. Off Rogaland the fishery is less intense than off Mid-Norway, but the season lasts longer, some boats working all year round. Further, the Rogaland fishery also targets smaller crabs, because the MLS since 1950 has been 2 cm smaller than in the other regions. There is no indication of females maturing smaller there (AKW, unpublished). How this smaller MLS may be influencing the catch rates and catch composition off Rogaland is not yet known.

Size distribution is often used as an indication of changes in stock structure and often forms an important component of stock assessment (Rochet and Trenkel, 2003). One clear pattern in the size distribution was the difference in CW between the southern region (Rogaland) and the more northern regions of Mid-Norway and Helgeland. The difference between exposed and sheltered fishing grounds was pronounced off Mid-Norway, sheltered grounds having a greater proportion of large females and fewer undersized crabs. Similar distribution patterns have been observed along coastal Norway (Woll, 1982), in the English Channel (Brown and Bennett, 1980; Bennett and Brown, 1983), and in the Bay of Biscay (Latrouite and Le Foll, 1989). Such a pattern is thought to be largely attributable to topographic and substratum variation, as well as different preferences for habitat between juveniles and adults. The absence of a similar pattern from Rogaland and Vesterålen is thought to be due to data limitation.

Edible crabs are poikilotherms, so increasing their oxygen consumption and intake of food with increasing temperature (Aldrich, 1975). South of Stad (62°N), the coastal water is influenced by an outflow of fresher, varying but generally higher temperature, water from the

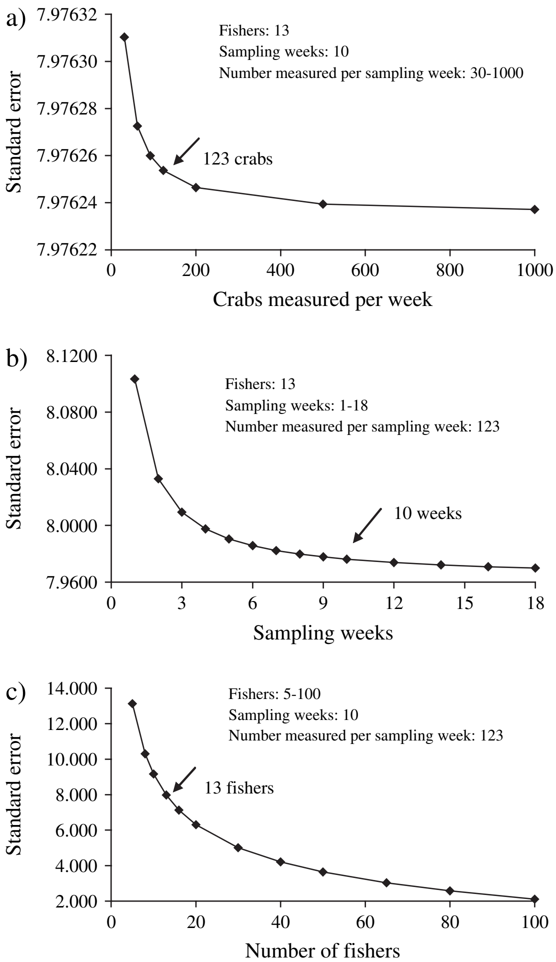

Figure 6. Precision of the estimate of mean CW of the edible crab as a function of (a) the number of crabs measured per week, (b) the number of reporting weeks per boat, and (c) the number of fishers in the reference fleet. The arrows denote the precision of the 2003 data from Mid-Norway.

Baltic Sea. Farther north the influence of the North Atlantic Current is more pronounced, and the water is more saline but has only moderate annual fluctuations in temperature. This might cause a geographical difference in the timing of growth of edible crabs through moulting, which may be reflected in the earlier moult and spawning time in the southernmost region (Rogaland). Such a pattern may cause differences in overall growth rate, as previously found between crab populations in the North Sea and the English Channel (Brown, 1975; Brown and Bennett, 1980).

Considered from another perspective, differences in stock structure may be due to between-region differences in genetic make-up. Hydrographic variations may influence larval dispersal in different ways. Eaton *et al.* (2003) found that the seasonality of prevalent current systems limited larval dispersal and led to the existence of several linked, but nevertheless distinguishable, populations in the North Sea. Future genetic studies may be able to throw light on such stock complexities, as shown for different stocks of coastal cod along the Norwegian coast (Knutsen *et al.*, 2003; Pogson and Fevolden, 2003).

Assessment and management regimes

Knowledge of a population's spatial and temporal distribution is essential in deciding on an optimal sampling procedure that seeks to describe biological parameters of a population. The results given here show that an increase in the number of fishers carrying out sampling seems to be the only way to attain a marked reduction in the variance of the mean CW estimated in all regions. Neither increasing number of crabs measured per week nor the total number of weeks each fisher carried out sampling would much influence the estimate of mean size. There is a clear variation in catch composition between fishers, but because the fishers were using identical gear, the conclusion is that there is marked local variation in the catch composition of different size groups of edible crab, and hence a strong spatial structure in distribution pattern of the population(s). There were also differences in size and sex composition of the catches between fishing ground exposure category for Mid-Norway, the only region for which there were sufficient data to carry out such an analysis. Such results match previous observations of fishers concerning between-region differences in catch composition. Also, earlier studies have shown that this observation may be connected to a preference of mature females for sandy substrata (Howards, 1982; Woll, 2003), which tend to be in more sheltered areas, smaller crabs often dominating exposed fishing grounds (Eriksen and Moen, 1993; Robinson and Tully, 2000). Such preferences would obviously influence a local catch composition.

Many assessment methods are used to underpin fishery management decisions, and several crab fisheries worldwide are assessed using commercial catch data such as cpue and lpue (Bjerkan, 1926; Edwards, 1989). Some of the problems with such data have already been discussed. Recently, therefore, fisheries logbook programmes that include space for biological data have been tested for some commercially important decapod crustacean fisheries, including edible crabs (Starr and Vignaux, 1997; Tully *et al.*, 2002; Anon., 2003; www.edfam.net). Mark-recapture studies and scientific research surveys are also used (Fogarty, 1995; Chen *et al.*, 2005). There is also some promise in the use of recruitment indices (Hall and Chubb, 2001; Gardner *et al.*, 2001; Steneck and Wilson, 2001; Bentley *et al.*, 2005), although such indices are not yet used for the crab fisheries of Europe, where traditional methods based on cpue and logbooks still prevail (Tully *et al.*, 2002). The Norwegian logbook programme seems to provide reliable data, provided that the fishers contributing to it are representative of the whole fishing community. Moreover, the programme has resulted in the collection of extensive information on sex ratio, mean size, and size distribution that is not available from other sources.

In 2004, commercial landings north of 63°N were for the first time separated by sex, facilitating comparison of such data with information from the logbook programme. The official percentage of females in the landed catch of Helgeland was 72.1%, very close to the percentage deduced from the logbook programme (72.6%). Comparisons of the sex composition of landings in Mid-Norway are not quite so similar. In Mid-Norway's North Trøndelag, the proportion of females was officially 74.1% and the logbook calculation 82.2%, and in South Trøndelag, the female proportions were 53.2% and 59.8%, respectively. It is thought that the slightly higher proportion of females registered in the logbook programme of Mid-Norway may be a consequence of selection by fishers.

The logbook programme is not suitable for calculating effort or overall catch rates in the fishery owing to the limited number of fishers participating. An evaluation of historical and new assessment data for crab stocks in British and Irish waters concluded that cpue data should be collected at a fine temporal and spatial scale, most effectively by completion of logbooks by the whole fleet (Tully *et al.*, 2002). About 400 vessels participate in the Norwegian commercial fishery for edible crab, and the ideal situation would have been for all to participate in the logbook scheme. However, obtaining handwritten data from every fisher would entail a massive workload in terms of collecting, capturing electronically, and analysing the data. Electronic logbook systems have been developed for crustacean fisheries in some countries (Tully *et al.*, 2002), allowing fishers to report their catch by punching the data directly into an on-board computer. However, such systems are costly and require fishers to have access to computers for storing and transmitting the data. As the crab fishing vessels in Norway are often small and a number are manned by quite elderly fishers not familiar with computers, such electronic logbook systems are not currently considered an option for the Norwegian fishery for edible crab.

Estimating lpue at each landing is less labour-intensive than the use of trial traps, as described in this study. At present, landings are recorded by fish sales organizations, and the only additional information needed is a record of the number of trap hauls. Provision of such information by more fishers would permit more accurate assessments of the fishery by scientists, and for the fishers themselves, the extra work would be less than required in providing detailed logbooks. A logbook system based on a reference fleet and a collection of lpue and effort data from all or at least a large number of fishers require little investment to initiate and deliver sufficient data to analyse stock status. This would appear to us to be the best way of monitoring the Norwegian fishery for edible crabs.

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