Catchability and the spatial distribution of fishing vessels

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Abstract: A central problem when using commercial catch per unit effort (CPUE) as an index of fish stock abundance is that fishing vessels search for concentrations of fish. For a given stock abundance, CPUE may become high if the vessels succeed in finding patches of fish and low if the vessels distribute their catching operations more randomly. In this work, the relationship between catchability and two measures of the degree of spatial concentration of a trawl fleet (the fleet's spatial extent and the fleet's degree of spatial patchiness) is investigated for four different fish stocks. The catchability of northeast Arctic cod (*Gadus morhua*) is strongly related to the fleet's degree of spatial concentration, but the relationship is weaker for northeast Arctic haddock (*Melanogrammus aeglefinus*), and no relationships appear for two saithe (*Pollachius virens*) stocks. Our findings suggest that adjusting CPUE with a measure of the fleet's average degree of concentration relates CPUE more strongly with abundance for migratory stocks.

Résumé : Les navires de pêche recherchent les concentrations de poissons, ce qui donne lieu à un problème sérieux lorsqu'on veut utiliser les données commerciales de prises par unité d'effort (CPUE) comme indice de l'abondance d'un stock de poissons. Pour une abondance donnée d'un stock, CPUE peut être élevé si les navires réussissent à trouver des regroupements de poissons et faible si les navires répartissent leurs opérations de pêche de façon plus aléatoire. Dans notre étude, nous examinons la relation entre la capturabilité et deux mesures du degré de concentration spatiale d'une flotte de chalutiers (la dispersion spatiale de la flotte et son degré de contagion) chez quatre stocks différents de poissons. La capturabilité des morues franches (*Gadus morhua*) du nord-est de l'Arctique est en forte corrélation avec le degré de concentration spatiale de la flotte, mais la relation est plus faible dans le cas des aiglefins (*Melanogrammus aeglefinus*) du nord-est de l'Arctique; pour deux stocks de goberges (*Pollachius virens*), il n'y a pas de relation. Nos résultats indiquent que l'ajustement de CPUE à l'aide d'une mesure du degré moyen de concentration de la flotte établit une meilleure relation entre CPUE et l'abondance des stocks de poissons migrateurs.

[Traduit par la Rédaction]

Introduction

Catch per unit effort (CPUE) from commercial fishing fleets is often used as an index of fish stock abundance. The traditional assumption is that the total catch (C) divided by the total effort (f) during a time period is proportional to the average population abundance (N) in the same period: $C/f = qN$, where q is the catchability coefficient (Ricker 1975; Gulland 1983). Catchability is in practice not constant between time periods, and the relationship between CPUE and stock abundance often seems to be nonlinear (Arreguín-Sánchez 1996; Harley et al. 2001). A major problem with commercial CPUE is that fishing vessels, to a varying degree, search for concentrations of fish rather than fishing randomly in the distributional area of the target species (Paloheimo and Dickie 1964). The catchability coefficient then becomes a function of the vessels' success in finding fish concentrations. A number of studies show that the area occupied by a fish stock is positively correlated with stock abundance (e.g., Winters and Wheeler 1985; Crecco and Overholz 1990; MacCall 1990). If vessels are able to locate fish concentrations independently of population size, catchability may increase with decreasing population size (Ulltang 1980). This principle, sometimes referred to as hyperstability or density-dependent catchability, has caused serious misinterpretations and errors when CPUE has been used as an index of stock abundance, e.g., the Norwegian spring-spawning herring (*Clupea harengus*) (Ulltang 1980) and the northern cod (*Gadus morhua*) stock off Newfoundland and Labrador (Rose and Kulka 1999).

It may be reasonable to assume that the fishing vessels' spatial distribution at a given time reflects the spatial distribution of the targeted fish population (Gillis and Peterman 1998; Gillis et al. 1993). However, the skippers' knowledge about the distribution of the fish varies (Swain and Sinclair 1994), and this knowledge is strongly influenced by the degree and type (competition or cooperation) of interaction between vessels, which can be quite complex (Hilborn and Walters 1992). The spatial distribution of the fleet may therefore vary even if the spatial distribution of the fish remains constant.

If the vessels in a fleet have a spatially concentrated distribution, it is likely that the vessels succeed in locating areas with high densities of fish (e.g., because the spatial distribution of fish is concentrated or the vessels cooperate). A fleet's degree of success in locating fish concentrations during a time period affects the proportion of the targeted fish stock cap-

Received 10 July 2002. Accepted 27 February 2003. Published on the NRC Research Press Web site at http://cjfas.nrc.ca on 8 April 2003.
J16985

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 doi: 10.1139/F03-018

tured in this period. Thus, if sufficient information about the distribution of vessels exists, it might be possible to use this information to explain some of the variation in catchability. In the present work, we test this by calculating two different indices of the degree of concentration in the Norwegian bottom trawl fleet. These measures are compared with catchability for the stocks of northeast Arctic cod (*Gadus morhua*), northeast Arctic haddock (*Melanogrammus aeglefinus*), northeast Arctic saithe (*Pollachius virens*), and North Sea saithe (*Pollachius virens*).

Material and methods

Data sets

Catch and effort data are based on recorded logbooks from the Norwegian bottom trawl fleet. The individual records include vessel, day, position according to a statistical area-location scheme (Fig. 1), species, catch, and hours trawled on the given date. Note that one statistical location is recorded for each vessel each day (this is the location where the largest catch was taken the given day), i.e., a day-by-day resolution of the data. For each of the analyzed stocks, logbook data are selected from the geographical area corresponding to the distributional area used in the assessment of the stock (ICES 2002, 2003; Fig. 2). The analysed time period is 1980–1997; after 1980, the information in logbooks became more accurate because of the introduction of fishery regulations. The reason for not using data after 1997 is that the virtual population analysis (VPA) estimates, which are used to estimate the catchability coefficient, are imprecise for the last years; the estimate for a given year gradually converges towards a stable value as new data are included in the analysis. Information about this convergence (retrospective analyses) was investigated (ICES 2002, 2003). Daily records with less than 15% of the analysed species in the catch are excluded to increase the probability that the species was targeted. Geographical positions in degrees are estimated as the midpoint in the recorded statistical locations (Figs. 1–3).

VPA estimates of trawlable biomass (age 3+) in the start of the year of northeast Arctic cod, northeast Arctic haddock, and northeast Arctic saithe are taken from ICES (2002), and corresponding estimates of North Sea saithe are taken from ICES (2003). A more detailed description of the selection of VPA data is given in Appendix A.

Spatial distribution of the fleet

Because fishing vessels search for concentrations of fish, the catchability is expected to increase when the area occupied by the stock decreases. Furthermore, when the interaction between vessels in a fleet changes (e.g., increased cooperation), the catchability is expected to change, even if the spatial structure of the stock remains constant. Given that the spatial distribution of the fleet gives an indication of the area occupied by the targeted fish population and (or) the degree of cooperation between vessels, two spatial measures may be important for the value of the catchability: the fleet's spatial extent and the fleet's degree of spatial patchiness (Fig. 4).

Degree of spatial extent

The daily degree of spatial extent of the fleet, D_d, is estimated by taking the average of all distances between pairs of vessels:

$$D_d = \frac{1}{n_d} \sum_{j,k} s_{jk} \tag{1}$$

where $n_d = n(n - 1)/2$ is the number of distances between vessels on day d, n is the number of vessels operating on day d, and s_{jk} is the distance between vessel j and vessel k (in nautical miles). Low values of D_d indicate that the fleet has a low degree of spatial extent.

Degree of spatial patchiness

The daily degree of patchiness in the spatial distribution of the fleet is estimated with the Clark–Evans index (Clark and Evans 1954). This index (termed R_{CE} in the present work) is widely used in ecology to measure the degree of patchiness in the spatial distribution of individuals:

$$R_{\mathrm{CE}} = \frac{\sum_{i=1}^{n} r_i}{N} 2\sqrt{P} \tag{2}$$

where r_i is the distance between individual i and its nearest neighbour, n is the number of such measurements, N is the number of individuals, and P is the density of the population (number of individuals per unit area). Low values of the index indicate that the spatial distribution of individuals is patchy. By assuming that the distributional area of the population (vessels) is constant and that the entire population is measured ($n = N$), R_{CE} is proportional to

$$R_d = \frac{\sum_{i=1}^{N} r_i}{\sqrt{N}} \tag{3}$$

where r_i now is the distance between vessel i and its nearest neighbour (in nautical miles), and N is the number of vessels operating on day d.

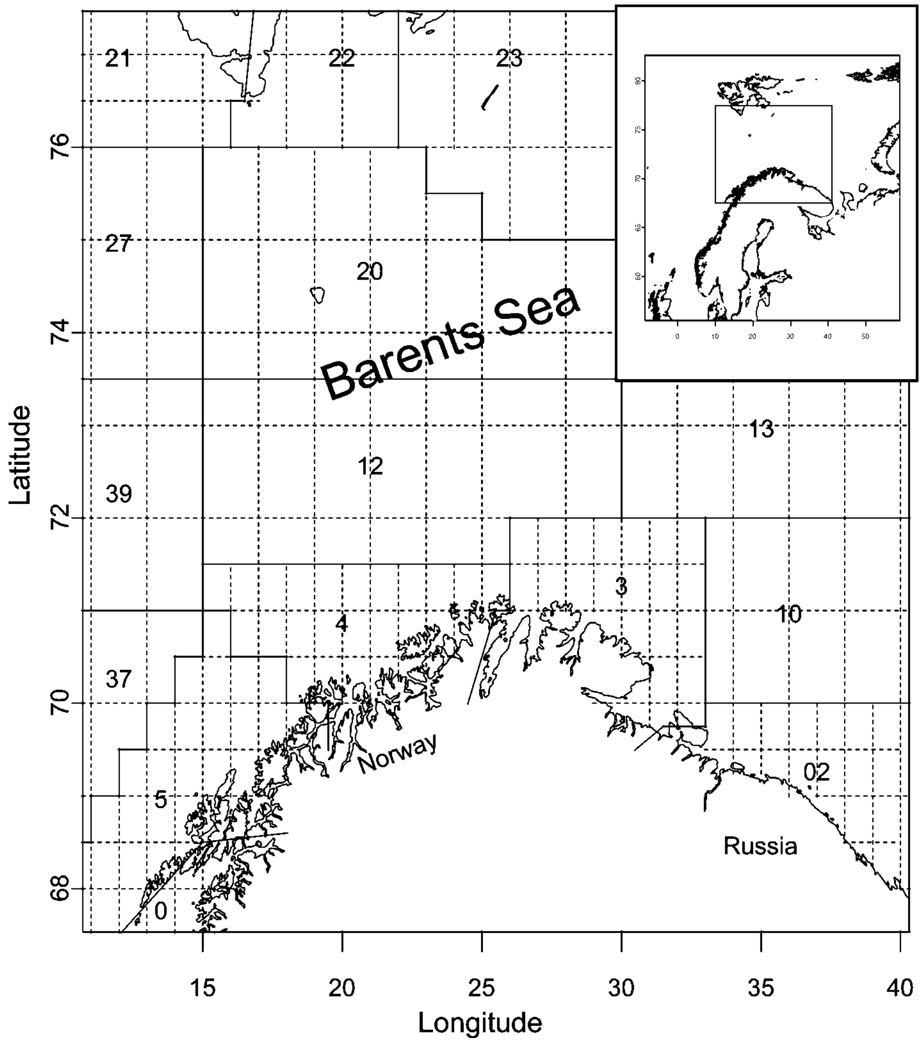
Comparison with catchability coefficients

Yearly catchability coefficients, q, are estimated for each of the four analysed stocks as follows:

$$q = C/Bf \tag{4}$$

where B is the abundance estimate in biomass (tonnes) of the trawlable part of the stock (see Appendix A), C is the summarised trawl catch (in tonnes × 10), and f is the summarised effort (in hours trawled). Because the estimates of B are given for the start of the year (t) the summations of catch and effort are conducted over the period from July in year $t - 1$ to June in year t. In this way, the estimate of B is given for the middle of the time period. It should be noted that CPUE from the Norwegian bottom trawl fleet not is used to calibrate (or tune) recent VPA estimates for northeast Arctic cod and northeast Arctic haddock (ICES 2003), thus B is independent of C and f. However, for the saithe stocks, there is a certain dependence between B and CPUE resulting from

Fig. 1. A part of the statistical area location scheme used by the Norwegian Directorate of Fisheries in the North Atlantic (statistical areas are numbered and delimited by solid lines, whereas statistical locations are delimited by dotted lines). The figure illustrates the resolution of the analyzed position data. The small inserted map shows the region from a broader perspective.



VPA tuning, but it is a limited problem in converged VPA (the last year in our analysis is 1997).

Yearly estimates of the fleet's spatial extent (D) and the fleet's degree of spatial patchiness (R) are calculated as weighted sums of the D_ds and R_ds over the year (where year is defined as the time period from July in year t – 1 to June in year t):

$$D = \frac{\sum N_d D_d}{\sum N_d} \quad (5)$$

$$R = \frac{\sum N_d R_d}{\sum N_d} \quad (6)$$

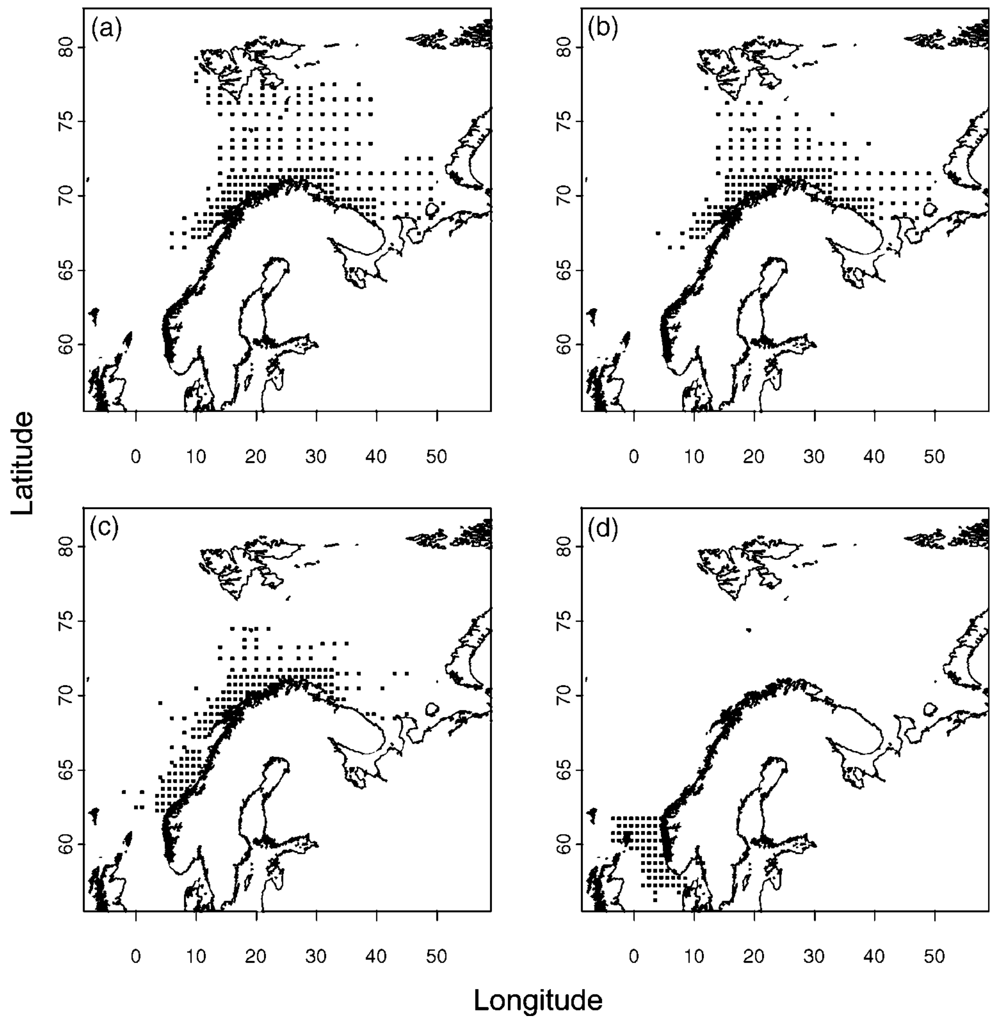
where N_d is the number of vessels operating on day d. Linear regression analyses between q and D and q and R are thereafter performed.

Extended analysis of northeast Arctic cod

Factors other than the vessels' search for concentrations of fish are also expected to lead to variation in the catchability coefficient. Two of these factors are differences in catching efficiency between vessels (Salthaug and Godø 2001) and the expected gradual increase in catching efficiency as the result of learning and technological improvements (Salthaug 2001). The effort (f in eq. 4) is adjusted for these two sources of error to investigate the effect on the relationship between q and D and q and R. First, the effort from individual vessels is adjusted for individual differences in catching efficiency, using the methodology described by Salthaug and Godø (2001). The principle in this methodology is to compare individual vessels' catching efficiencies when they are fishing at the same time and place, and then estimate a relative power factor for each vessel relative to a standard vessel. Power factors are estimated within 4-year periods, and the effort in each observation is adjusted to the standard vessel's level using these factors (the same standard vessel is used between the 4-year periods). Second, the standardised effort in each year i (f_i) is adjusted with a learning curve model (corrected eq. 4 in Salthaug 2001):

$$f_i^* = f_i\left(\frac{\mathrm{EPSF}_i}{\mathrm{EPSF}_{1981}}\right) \quad (7)$$

Fig. 2. Geographical area from which recorded logbook data are selected; recorded positions (■) (midpoint in statistical locations with at least two records during the analyzed time period) with catches of (*a*) northeast Arctic cod (*Gadus morhua*), (*b*) northeast Arctic haddock (*Melanogrammus aeglefinus*), (*c*) northeast Arctic saithe (*Pollachius virens*), and (*d*) North Sea saithe (*Pollachius virens*). This figure also illustrates the resolution of the analyzed position data.



where f_i^* is the adjusted effort in year *i*, $EPSF_i$ and $EPSF_{1981}$ are the effort per stock fraction modelled with the estimated learning curve model on vessel level (see fig. 1D in Salthaug 2001) in year *i* and 1981, respectively.

Because the catchability often seems to be density or stock size dependent, the relationships between trawlable biomass and *D* and *R* are explored. Changes in abundance may affect the spatial distribution of the fleet and of the stock and hence catchability.

The relationship between *R* and *D* is also briefly investigated for quarterly (eqs. 5 and 6 is used for quarter) and yearly estimates. By calculating *R*s and *D*s for each quarter, their seasonal dynamics are illustrated.

Results

The catchability of northeast Arctic cod is highly negatively correlated ($p < 0.05$), both with the spatial extent of the fleet (Fig. 5*a*) and with the degree of patchiness in the spatial distribution of the fleet (Fig. 6*a*), and the correlation with patchiness is strongest. Note that low values of spatial extent (*D*) and patchiness (*R*) indicate that the fleet is aggregated. The catchability of northeast Arctic haddock is also significantly ($p < 0.05$) negatively correlated, both with the spatial extent of the fleet (Fig. 5*b*) and with the degree of patchiness in the spatial distribution of the fleet (Fig. 6*b*), but these correlations are lower than for cod. For the two analysed stocks of saithe, the correlations are poor ($p > 0.05$), both between catchability and the spatial extent of the fleet (Figs. 5*c*, 5*d*) and between catchability and the degree of patchiness in the spatial distribution of the fleet (Figs. 6*c*, 6*d*). Note that the catchability coefficients vary extensively between years, especially for saithe and haddock. (Parameter estimates for the fitted regression lines in Figs. 5–8 are given in Table 1.)

After adjustment of the effort for individual differences in catching efficiency, the correlation between catchability of northeast Arctic cod and the spatial extent of the fleet decreases (Fig. 7*a*), and the slope becomes more flat (Table 1). This is similar for the relationship between catchability and the fleet's degree of spatial patchiness (Fig. 7*b* and Table 1), although the correlation does not decrease much.

Fig. 3. Recorded positions (■) of Norwegian trawlers in the Barents Sea targeting cod (*Gadus morhua*) on two different days: (*a*) 12 February 1999 and (*b*) 9 September 1999. Note that the same position may be recorded for more than one vessel on a given day, i.e., the number of operating vessels is normally higher than the number of different recorded positions.

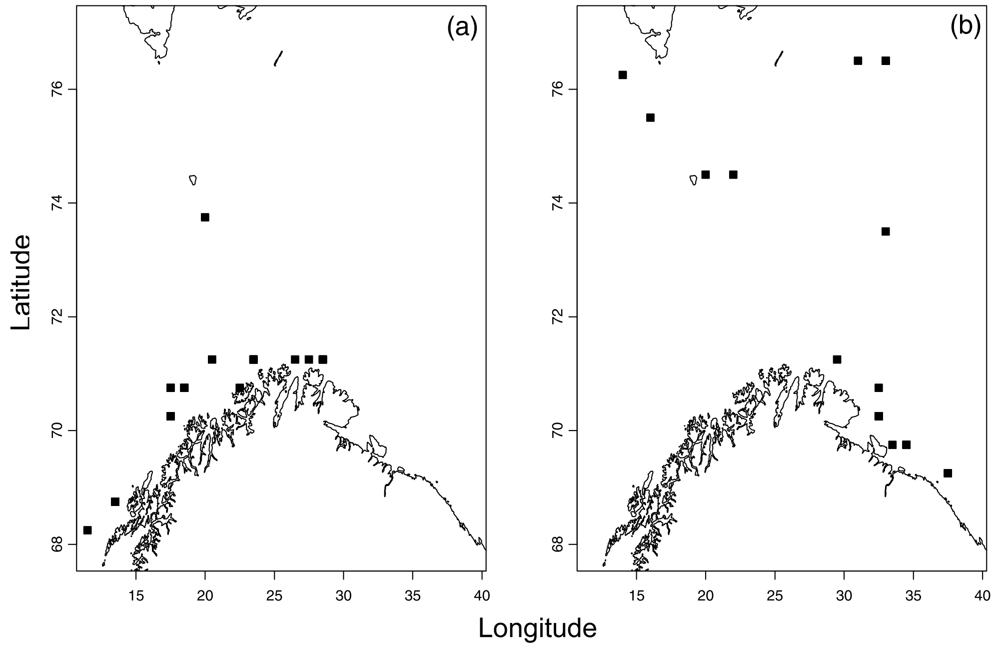
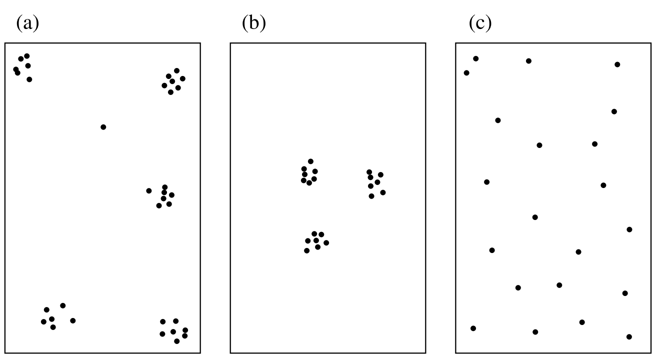


Fig. 4. Illustration of vessels (●) in a fleet in which the vessels have (*a*) a high degree of spatial extent and a high degree of spatial patchiness (i.e., high *D* and low *R*), (*b*) a low degree of spatial extent and a high degree of spatial patchiness (i.e., low *D* and low *R*), or (*c*) a high degree of spatial extent and a low degree of spatial patchiness (i.e., high *D* and high *R*).



When the standardised effort is adjusted with the learning curve, both the correlation between catchability and the spatial extent of the fleet (Fig. 7*c*) and the correlation between catchability and the fleet's degree of spatial patchiness (Fig. 7*d*) become strong ($p < 0.01$), and the slopes decrease. However, neither the slopes of the fitted regression lines between catchability and the spatial extent of the fleet (Figs. 5*a*, 7*a*, 7*b*) nor those between catchability and the fleet's degree of spatial patchiness (Figs. 6*a*, 7*b*, 7*d*) are significantly different ($p > 0.05$).

The spatial extent of the fleet is highly positively correlated with the trawlable biomass of northeast Arctic cod (Fig. 8*a*), though the relationship seems nonlinear. The linear relationship between trawlable stock biomass and the degree of patchiness in the spatial distribution of the fleet is weaker (Fig. 8*b*), but the slope is positive and the correlation is slightly significant ($p < 0.05$).

The fleet's spatial extent and degree of spatial patchiness are highly correlated in the first part of the analyzed time period, but the correlation decreases in the last part of the period (Figs. 9*a*, 9*b*). The seasonal variation in both the fleet's extent and degree of spatial patchiness is extensive (Fig. 9*a*), with high values in quarters 3 and 4 relative to quarters 1 and 2 (see also Fig. 3). The observed pattern (Figs. 9*a*, 9*b*) is similar for the other stocks except for northeast Arctic saithe.

Discussion

The important finding in this work is the strong linear relationship between the catchability of northeast Arctic cod and the fleet's degree of spatial concentration (measured by spatial extent and patchiness). A linear relationship is also the case for northeast Arctic haddock, although the relationship seems to be somewhat weaker. It is difficult to conclude, based on the results, which of the two measures of the fleet's spatial concentration that have the strongest relationship with catchability.

It may be questioned why northeast Arctic cod is the stock with the clearest linear relationship between catchability and the degree of concentration in the spatial distribution of the fleet. First, it is important that the analysed species is targeted; the distribution of the fleet is not expected to follow the distribution of the fish for a by-catch species. Being the most economically important species in the Barents Sea, cod is a typical target species for trawlers. On the other hand, haddock is often taken as by-catch in the fishery for cod (Salthaug and Godø 2000), and this may explain the poorer fit in our results. Second, the spatial structure and distribution of the investigated fish population must vary between years (this is typical for migratory species like cod, haddock, and many

Fig. 5. Catchability coefficient (q) and the average extent in the spatial distribution of the trawl fleet (D) for (a) northeast Arctic cod (*Gadus morhua*), (b) northeast Arctic haddock (*Melanogrammus aeglefinus*), (c) northeast Arctic saithe (*Pollachius virens*), and (d) North Sea saithe (*Pollachius virens*). Linear regression lines are shown, and corresponding equations are given in Table 1. The r^2 value refers the amount of variation described by the linear model and p values to H_0: slope = 0.

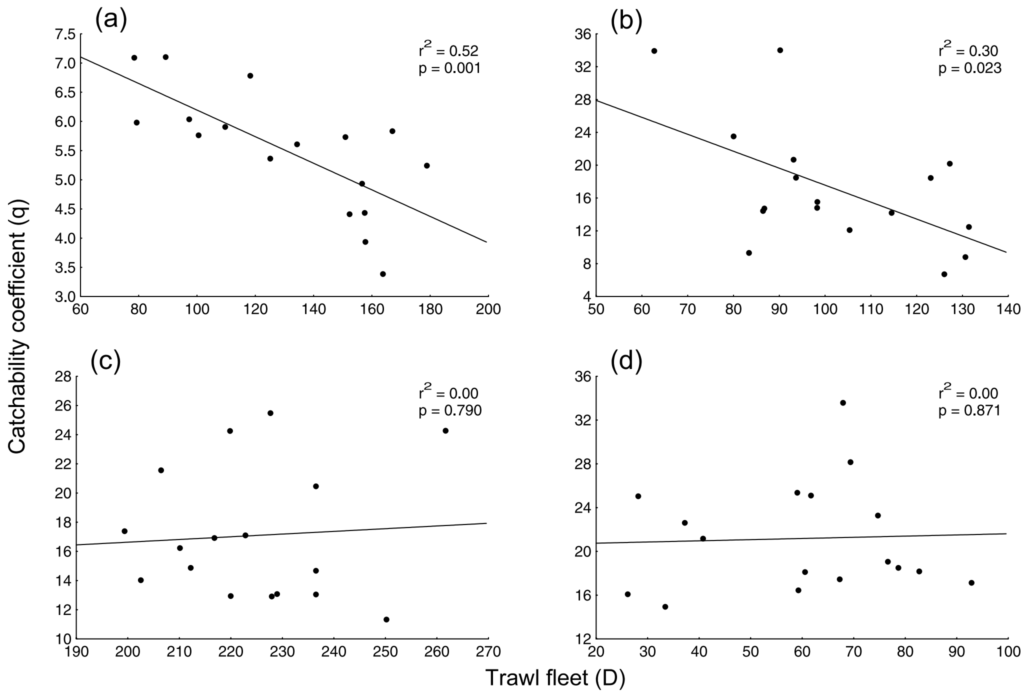
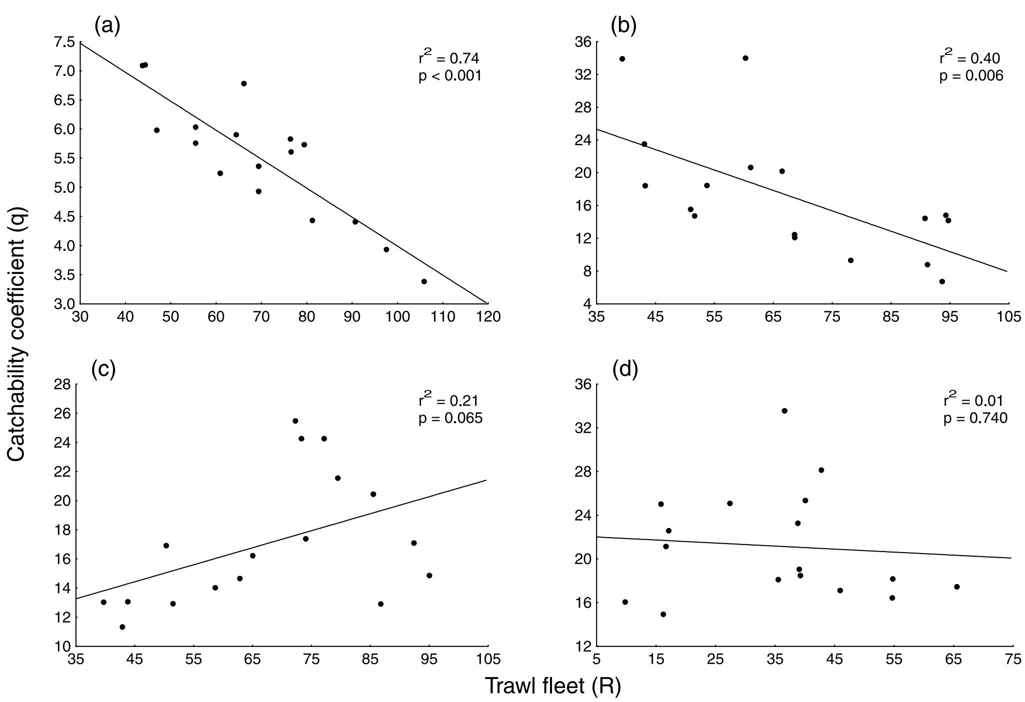


Fig. 6. Catchability coefficient (q) and the average degree of patchiness in the spatial distribution of the trawl fleet (R) for (a) northeast Arctic cod (*Gadus morhua*), (b) northeast Arctic haddock (*Melanogrammus aeglefinus*), (c) northeast Arctic saithe (*Pollachius virens*), and (d) North Sea saithe (*Pollachius virens*). Linear regression lines are shown, and corresponding equations are given in Table 1. The r^2 value refers the amount of variation described by the linear model and p values to H_0: slope = 0.



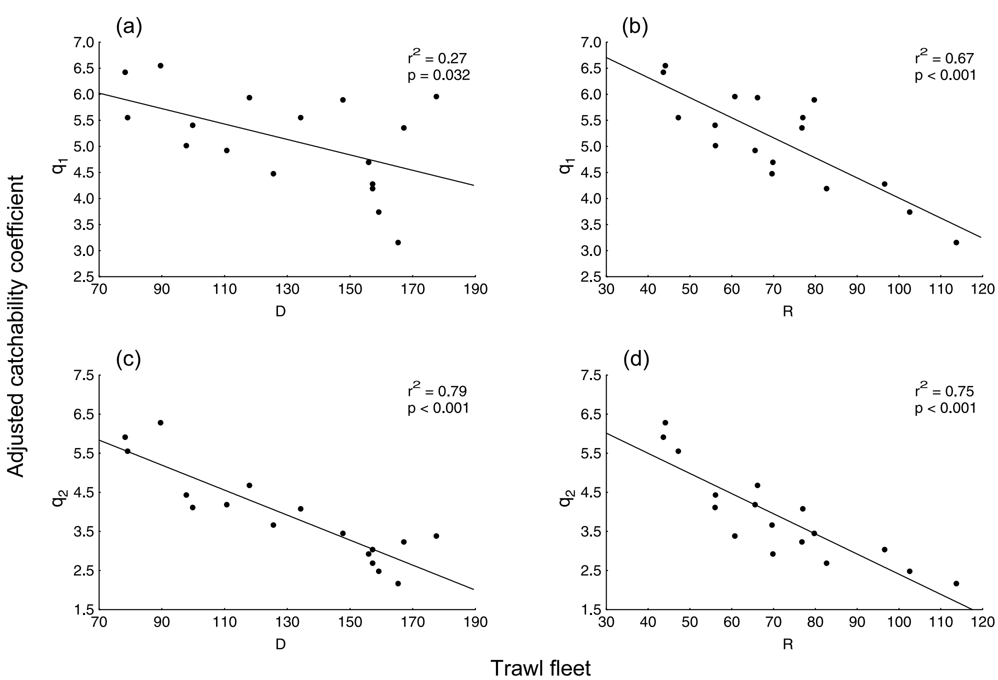
pelagic species). The two analysed saithe stocks are targeted, but the Norwegian trawl fisheries are conducted in fairly concentrated areas: northeast Arctic saithe are taken along the coast and North Sea saithe are taken along the northern continental slope in the North Sea. The resolution of the position data may therefore be too low to depict the spatial dynamics

Table 1. Fitted linear models between catchability (q), the fleet's degree of spatial extent (D), the fleet's degree of spatial patchiness (R), and trawlable stock biomass (B, in tonnes) for the analyzed species (the last column shows the corresponding figures).

Fitted model	Species	Figure
q = 8.47 – 0.023D***	Northeast Arctic cod (*Gadus morhua*)	5*a*
q = 38.22 – 0.207D**	Northeast Arctic haddock (*Melanogrammus aeglefinus*)	5*b*
q = 12.93 + 0.019D*	Northeast Arctic saithe (*Pollachius virens*)	5*c*
q = 20.54 + 0.011D*	North Sea saithe (*Pollachius virens*)	5*d*
q = 8.96 – 0.050R***	Northeast Arctic cod (*Gadus morhua*)	6*a*
q = 34.03 – 0.249R***	Northeast Arctic haddock	6*b*
q = 9.18 + 0.117R*	Northeast Arctic saithe	6*c*
q = 22.15 – 0.028R*	North Sea saithe	6*d*
$q_1{}^a$ = 7.06 – 0.015D**	Northeast Arctic cod	7*a*
$q_1{}^a$ = 7.86 – 0.039R***	Northeast Arctic cod	7*b*
$q_2{}^b$ = 8.08 – 0.032D***	Northeast Arctic cod	7*c*
$q_2{}^b$ = 7.56 – 0.052R***	Northeast Arctic cod	7*d*
D = 66.34 + 4.88 × 10^{-5} B***	Northeast Arctic cod	8*a*
R = 43.66 + 2.08 × 10^{-5} B**	Northeast Arctic cod	8*b*

Note: For more information about the model fits (r^2 and p values), see Figs. 5–8. *, $p > 0.05$; **, $p < 0.05$; ***, $p < 0.01$.
[a]Catchability is adjusted for individual differences in catching efficiency (see text).
[b]Catchability is adjusted for individual differences in catching efficiency and learning (see text).

Fig. 7. Catchability coefficient for northeast Arctic cod (*Gadus morhua*) when the effort is adjusted for individual differences in catching efficiency (q_1) and (*a*) the average extent in the spatial distribution of the trawl fleet (D) and (*b*) the average degree of patchiness in the spatial distribution of the trawl fleet (R). Catchability coefficient for northeast Arctic cod (*Gadus morhua*) when the effort is adjusted for individual differences in catching efficiency and learning (q_2) and (*c*) the average extent in the spatial distribution of the trawl fleet (D) and (*d*) the average degree of patchiness in the spatial distribution of the trawl fleet (R). Linear regression lines are shown and corresponding equations are given in Table 1. The r^2 value refers the amount of variation described by the linear model and p values to H_0: slope = 0.



of the fleet. It is likely that a recorded position for each trawl haul (instead of a daily statistical location) would have given a better relationship between catchability and the degree of patchiness in the spatial distribution of the fleet for the saithe stocks.

The analyses in the present work require precise estimates of the catchability coefficients. It is generally difficult to estimate the trawlable part of a fish stock (B in eq. 4), and the assumption that the biomass of age 3+ is trawlable may be questioned. The relative fishing pressure on different age groups probably varies to a certain extent throughout the season (e.g., as the result of mesh selection and market prizes for different sizes of fish), and the age composition in the stock varies. This variation may therefore lead to varia-

Fig. 8. Trawlable biomass of northeast Arctic cod (*Gadus morhua*) (age 3+ from VPA) and (*a*) the average extent in the spatial distribution of the trawl fleet (*D*) and (*b*) the average degree of patchiness in the spatial distribution of the trawl fleet (*R*). Linear regression lines are shown and corresponding equations are given in Table 1. The r^2 value refers the amount of variation described by the linear model and *p* values to H_0: slope = 0. Only records from vessels for which effort is adjusted for individual differences in catching efficiency are used to calculate *R* and *D*.

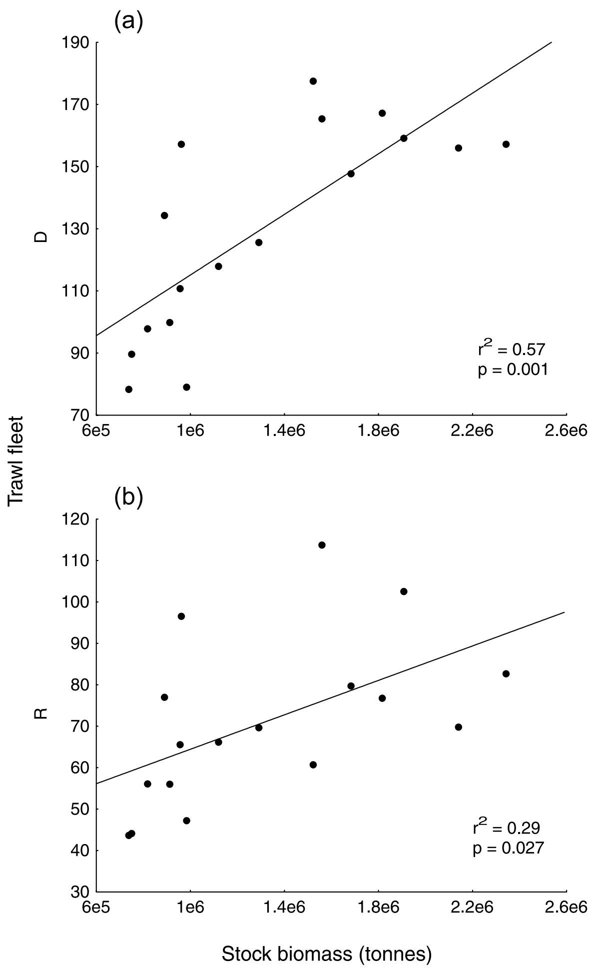
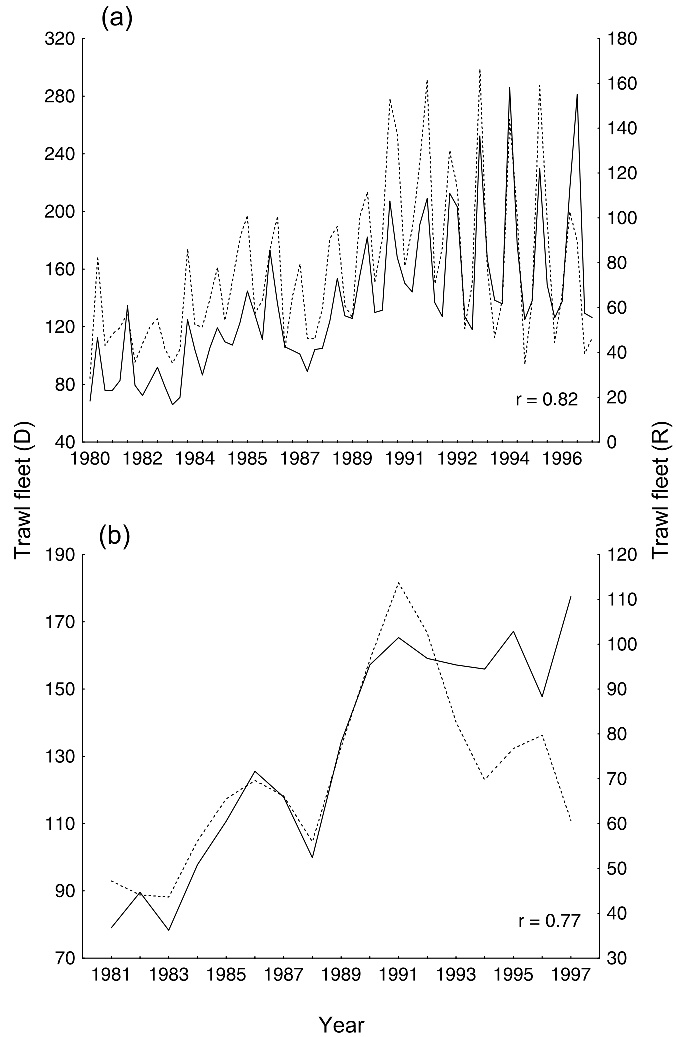


Fig. 9. Time series of *R* (broken line) and *D* (solid line) for northeast Arctic cod (*Gadus morhua*): (*a*) quarterly and (*b*) yearly *R*s and *D*s. Only records from vessels for which effort is adjusted for individual differences in catching efficiency are used to calculate *R* and *D*. The correlation (*r*) is inserted.



tion in the catchability coefficient. In addition, VPA-based abundance estimates are generally uncertain because of inaccurate catch reports and sampling errors. The VPA estimates of northeast Arctic cod are probably more precise than the estimates of the other three stocks as the result of more extensive age sampling. Detailed information about the age composition in catches together with better position data would have made it possible to calculate age-disaggregated CPUE. Abundance indices from scientific surveys could then have been used, in addition to VPA estimates, to estimate age-specific catchability coefficients (because of a number of error sources, it is difficult to obtain a reliable survey estimate of trawlable stock biomass).

The fact that the relationship between catchability of northeast Arctic cod and the fleet's degree of spatial concentration becomes improved when the effort is adjusted for both individual differences in catching efficiency and learning indicates that it is important to adjust CPUE for other sources of error (although, for our data, the models are not significantly different). However, the interactions between individual differences in catching efficiency, learning, and spatial dynamics of the fleet (e.g., the degree of spatial concentration) are quite complex, which makes it difficult to construct adequate correction models.

It is indicated that the area occupied by the northeast Arctic cod stock increases when the biomass increases because the spatial extent of the fleet increases with increasing biomass. The area occupied by other stocks of cod has also been shown to be positively correlated with abundance (Rose and Leggett 1991; Atkinson et al. 1997; Rose and Kulka 1999). Our results show that the relationship between trawlable biomass and the fleets' degree of patchiness is much more scattered than the former. Thus, avoiding hyperstability by using models where the catchability increases as the stock abundance decreases may be too simple; the catchability may, for example, stay high even if the stock abundance is high, given that the stock has an aggregated distribution and the fishing vessels succeed in finding these aggregations.

Both the fleet's spatial extent and the fleet's degree of spatial patchiness vary extensively during the season. This is expected as most migratory fish stocks have a seasonal variation in their spatial distribution and the fleet follows the fish. This variation can lead to additional noise when calculating yearly indices of a fleet's spatial distribution if the temporal distribution of effort within the year changes between years (this is also a problem when calculating yearly CPUE). However, earlier analyses of the Norwegian bottom trawl fleet have revealed that the seasonal distribution of effort is fairly constant.

A widely used method for adjustment of CPUE for geographical concentration of effort is to spatially stratify the distributional area of the population and use a stratified average as the abundance index (Gulland 1956). More complex methods of various kinds of spatial interpolation techniques also exist (Hilborn and Walters 1992). However, a major problem with these methods is that the abundance estimate is highly sensitive to the assumptions about the number of individuals in the areas where no fishing occurs (Hilborn and Walters 1992). In highly migratory stocks, such as the northeast Arctic cod and pelagic stocks, there will always be large areas without fishing activity. Correction of catchability with the degree of concentration in the spatial distribution of the fleet seems to be an alternative and promising approach for such stocks.

Acknowledgments

We thank the Research Council of Norway for financial support, Michael Pennington for improving the manuscript, and two anonymous referees for valuable comments.

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Appendix A

It is here described how the trawlable parts (*B* in eq. 4) are selected from the VPA estimates for the start of each year (trawlable biomass is defined as age 3+ for all four stocks).

Northeast Arctic cod

Trawlable biomass is "TOTALBIO" in table 3.24 in ICES (2002).

Northeast Arctic haddock

Trawlable biomass is "TOTALBIO" in table 4.16 in ICES (2002).

Northeast Arctic saithe

Trawlable biomass is calculated by subtracting the biomass of age 2 in table 5.9 from “TOTAL” in table 5.9 in ICES (2002).

North Sea saithe

Trawlable biomass is calculated by subtracting the biomass of age 1 and age 2 from “TOTALBIO” in table 6.6.1 in ICES (2003). The biomasses of age 1 and age 2 are calculated by multiplying the weights at age in table 6.2.3 by the VPA numbers at age in table 6.4.3.