Discarding practices for commercial gadoids in the North Sea

Yorgos Stratoudakis, Robert J. Fryer, and Robin M. Cook

Abstract: Understanding fishers' discarding behaviour, and anticipating their reactions to changes in the biological or regulatory characteristics of a fishery, are important for dealing with the problem of discarding. In this paper, we investigate the discarding of haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and Atlantic cod (*Gadus morhua*) in the North Sea, using data collected by scientific observers onboard Scottish demersal vessels. We describe discarding on each trip by species-specific discard curves and explore how these curves depend on biological and regulatory variables. There are large differences in the size of discarded fish between inshore and offshore areas, with offshore-operating vessels discarding larger fish (high-grading). Increases in legal landing size correspond to immediate increases in the size of discarded fish, particularly for haddock and cod in inshore areas. In general, discarding practices for haddock and cod are similar over time and consistent across gears, whereas decisions for the lesser valued whiting are more variable and can be affected by the catch composition.

Résumé : Si l'on veut régler le problème du rejet des poissons par les pêcheurs, il est important de comprendre le comportement des pêcheurs et de prévoir leur réaction face à la modification des caractéristiques biologiques ou réglementaires d'une pêche. Dans le présent article, nous examinons le rejet de l'aiglefin (*Melanogrammus aeglefinus*), du merlan (*Merlangius merlangus*) et de la morue en mer du Nord (*Gadus morhua*) à l'aide de données recueillies par des observateurs scientifiques à bord de bateaux écossais de pêche du poisson de fond. Nous décrivons les rejets effectués lors de chaque sortie à l'aide de courbes de rejets en fonction de l'espèce, et nous analysons dans quelle mesure ces courbes dépendent de variables biologiques et réglementaires. Nous observons des différences importantes entre la taille des poissons rejetés dans les zones côtières et ceux rejetés dans les zones du large : les bateaux travaillant au large rejettent des poissons plus gros (écrémage). L'accroissement de la taille légale des poissons débarqués correspond à des augmentations immédiates de la taille des poissons rejetés, en particulier de l'aiglefin et de la morue dans les zones côtières. En général, les rejets d'aiglefin et de morue sont similaires dans le temps et uniformes d'un engin à l'autre, tandis que les décisions relatives au merlan, espèce moins prisée, sont plus variables, et peuvent être influencées par la composition des captures.

[Traduit par la Rédaction]

Introduction

Discarding fish to the sea has for some time been accepted as an inevitable component of harvest fisheries. Recent estimates suggest that more than one quarter of all fish caught annually are wasted through discarding (Alverson et al. 1994). Such estimates help to appreciate the magnitude of the phenomenon and gradually lead to the situation where discarding is becoming a major management issue (Alverson and Hughes 1996). However, the decision to discard is taken on deck and is therefore largely a function of fishers' behaviour (Hilborn 1985). Understanding this behaviour and anticipating fishers' reactions to changes in the biological or regulatory characteristics of a fishery are important for dealing with the problem and reducing the waste.

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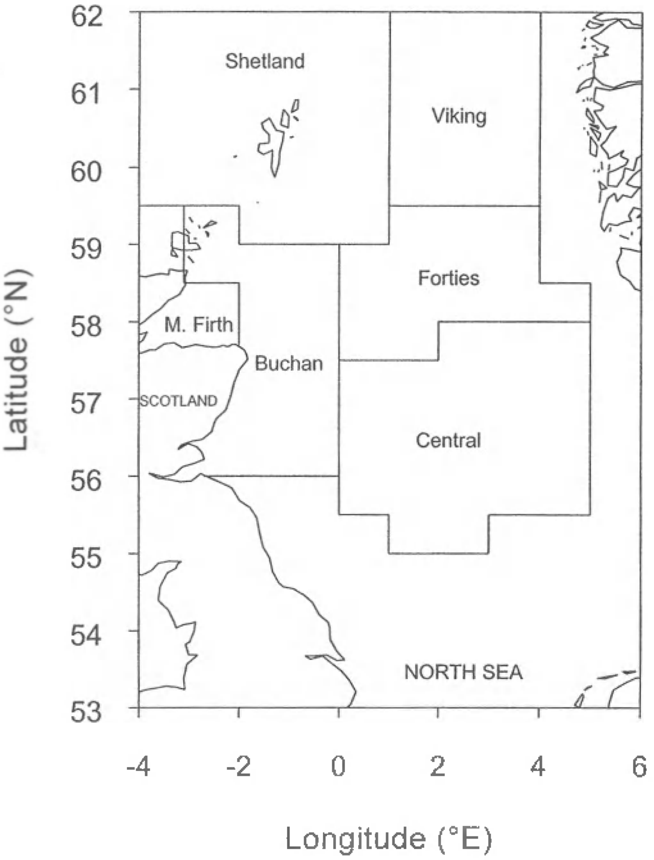
Y. Stratoudakis.[1] Marine Laboratory, Victoria Road, AB11 9DB, Aberdeen, U.K., and Department of Zoology, University of Aberdeen, Tillydrone Avenue, AB24 2TZ, Aberdeen, U.K.
R.J. Fryer and R.M. Cook. Marine Laboratory, Victoria Road, AB11 9DB, Aberdeen, U.K.

[1] Present address: Instituto de Investigação des Pescas e do Mar, Avenida de Brasilia, 1400 Lisboa, Portugal.

For unmarketable species the process is straightforward, because the entire catch is dumped overboard. For species with a commercial interest (target or bycatch), many factors can influence the final decision on whether to discard. These range from fisheries regulations and biological properties of the fished stocks to market forces and fishers' personal preferences (Crean and Symes 1994). The situation is particularly complicated in mixed-species demersal fisheries, where several considerations intermingle to create a complex and dynamic discarding behaviour (Pikitch 1991). Sampson (1994) and Gillis et al. (1995*a*, 1995*b*) applied ideas from behavioural ecology and microeconomics to elucidate aspects of the decision-making involved in discarding. However, these studies are based on analytical approaches that make minimal use of actual discards data.

In this paper, we investigate discarding practices using field data, rather than a theoretical approach. The data come from the Scottish discards sampling programme (Jermyn and Robb 1981), which sends scientific observers on commercial fishing trips. Whilst onboard, the observers monitor the fishing operation and obtain species-specific length frequencies of landings and discards. Here, we investigate how the proportions of each species discarded at length depend on various biological and regulatory variables. In particular, we examine the effect of fishing area and gear, quarter of the year, landing harbour, and the composition of the catch. Further, we examine temporal

Fig. 1. Stratification of the North Sea for the Scottish discards sampling programme.



changes in the proportion discarded at length and associate them with changes in the management measures that prevail in the North Sea demersal fisheries.

We consider discarding by Scottish vessels using demersal mobile gears in the North Sea and focus on haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and Atlantic cod (*Gadus morhua*), the three most important target species. The study covers the period 1975–1993, during which many aspects of the North Sea fisheries have changed (Symes 1992; Hislop 1996). These include biological changes, such as the reduction of some stocks to historically low levels, and regulatory changes, such as increases in nominal mesh size and minimum landing size.

Materials and methods

The Scottish discards sampling programme

Regular sampling of discards by scientific observers onboard U.K. vessels fishing in the North Sea and landing in Scotland began in 1975 and continues to the present day. The main objective of the programme is to provide annual estimates of the total quantities of the major commercial gadoids discarded in the North Sea (see Jermyn and Robb 1981). Cooperation in the programme by fishing vessels is on a voluntary basis.

The programme is based on stratified random sampling by area (Fig. 1), quarter of the year (January to March, etc.), and gear. Sampling concentrates on mobile demersal gears (trawlers and seiners) that are mainly used for catching gadoids and produce many discards in the process (Alverson et al. 1994). Resource limitations usually restrict sampling to one trip in each stratum where more than 10 000 h of fishing is expected (Jermyn and Robb 1981). As a result, the coverage is always small, ranging between 0.1 and 0.2% annually, both in terms of effort and landings. A sampling trip is defined to be the period spent away from the harbour until return for landing. This can vary from 1 day for small inshore vessels, to 2 weeks for larger vessels operating in the open sea. Sometimes, the fishing area or the operating gear change while the observer is onboard, and these are treated as separate trips.

Table 1 shows the number of trips sampled by area and gear. They are separated into the periods 1975–1984 and 1985–1993 to show how fishing methods, and hence sampling effort, have changed over the study period. Early sampling was concentrated on heavy trawlers (vessels larger than 27.5 m) and seiners. Light trawlers (vessels smaller than 27.5 m) became more important later, as fishing by heavy trawlers declined and many seiners converted to trawling. *Nephrops* trawlers (trawlers targeting the Norway lobster, *Nephrops norvegicus*) were first sampled in 1982, and pair trawlers (demersal trawlers operating in pairs) in 1986. In total, 982 trips on 242 vessels landing in 19 Scottish harbours were sampled during the study period, with an average of 23 h fishing observed per trip.

Discard summary statistics

While onboard, the scientific observers collect samples of the sorted catch to estimate discards and landings length frequencies of the three targeted gadoids (haddock, whiting, and cod). Numbers landed and discarded at length can be combined to calculate the proportion of the species catch discarded at length. Our aim is to explore, for each species in turn, how the proportion of fish discarded at length depends on biological and regulatory variables. To do so, we first describe the proportions discarded at length on each trip by two summary statistics. We then model the relationship between these summary statistics and the explanatory variables.

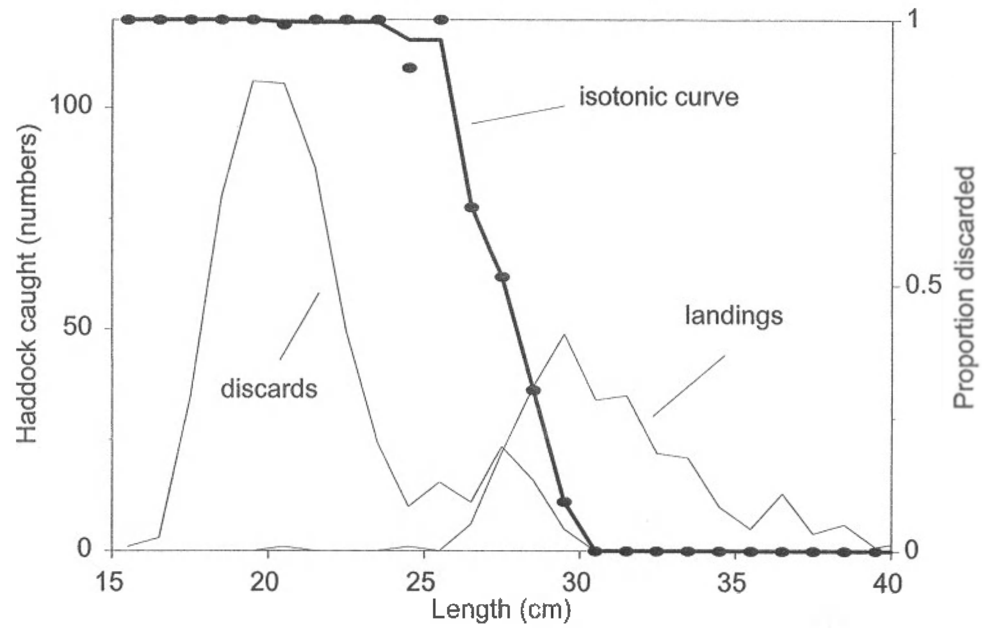
The proportions discarded at length can be thought of as coming from an underlying discard curve that relates the probability of discarding a fish to its length. The concept was introduced by Jean (1963) and is similar to that of gear selection curves (Wileman et al. 1996), only here the selection is imposed by the fishers, rather than the net. Intuitively, discard curves should be nonincreasing functions of length, and the data confirm this to be so; see Fig. 2, for example. Gear selection curves are usually summarized by two statistics that measure their location (length at which 50% of the fish are retained in the codend; L_{50}) and spread (the difference between the 75 and 25% retention lengths; interquartile range). In a similar way, we summarize the location of the discard curves by the species-specific discarding L_{50} (DL_{50}) and the spread by the discarding interquartile range. However, analysis of the discarding interquartile range did not reveal any systematic dependency on the explanatory variables (Stratoudakis 1997), and in the rest of this paper we concentrate on DL_{50}.

To estimate DL_{50}, we first have to fit a discard curve to the data for each trip. Techniques for estimating gear selection curves (Wileman et al. 1996) can easily be adapted for doing so. One option would be to fit a logistic curve (McCullagh and Nelder 1989). However, we fitted nonparametric isotonic curves that assume only that the curves are nonincreasing (Barlow et al. 1972; Millar 1993). The advantage of these curves is that they can describe both symmetric and asymmetric discarding patterns. A fitted isotonic discard curve is shown in Fig. 2. We then estimated DL_{50} by linearly interpolating between the fitted proportions of the isotonic discard curve. However, DL_{50} cannot be estimated when the species is not caught or when the entire species catch is discarded (particularly common in *Nephrops* trawlers where fish can legally be landed only in small amounts). Such trips were excluded from this analysis, resulting in slightly different data sets being used for modelling haddock, whiting, and cod DL_{50}s. Figure 3 shows summary box and whisker plots of the estimates of DL_{50} by species, excluding those from *Nephrops* trawlers. The range of

Table 1. Number of trips sampled by area and gear in the North Sea for 1975–1984 and 1985–1993.

	1975–1984					1985–1993				
Area	Heavy trawl	Seine	Light trawl	*Nephrops* trawl	Pair trawl	Heavy trawl	Seine	Light trawl	*Nephrops* trawl	Pair trawl
Shetland	38	61	8	—	—	4	37	19	—	21
Viking	—	28	—	—	—	1	25	2	—	2
Forties	—	24	—	—	—	—	24	6	2	5
Central	—	31	—	—	—	—	26	7	—	2
Moray Firth	—	41	11	18	—	—	36	22	52	2
Buchan	38	64	27	17	—	7	62	64	59	45
Other	8	1	2	—	—	2	17	8	3	1
Total	84	252	48	35	—	14	227	128	116	78

Fig. 2. An example of the methodology used to summarize the data from a sampled trip. Length frequencies for haddock discards and haddock landings from a seine trip in Buchan (June 1979), with the proportion of discards at length and the fitted isotonic curve.



estimates for cod is much wider than for haddock and whiting, possibly reflecting the scarcity of cod data.

We also estimated the standard error of each DL_{50} using bootstrap techniques (Efron and Tibshirani 1993). This can be thought of as measuring the "within-trip" variability associated with estimating DL_{50} and could be used later to correctly model the variance structure of the DL_{50}s in terms of within-trip and among-trip components of variation. However, exploratory analysis showed that, for haddock and whiting, the within-trip variability was much smaller than the among-trip variability and could effectively be ignored. The situation is less clear for cod (and for *Nephrops* trawlers), for which fewer fish are generally caught per trip, but for simplicity, we have ignored the within-trip component of variation throughout.

Explanatory variables

The explanatory variables available for this study can be conveniently grouped into three categories: catch variables measured during each trip, stratification variables associated with the selection of the vessel, and annual variables that change over time.

Catch variables

Detailed biological information is collected on each trip, so there are many ways of measuring the catch (i.e., discards plus landings) on that trip. We use the following, that seem to capture the broad features of the catch: (*i*) haddock catch per unit effort in kilograms per hour (HCPUE); (*ii*) whiting catch per unit effort in kilograms per hour (WCPUE); (*iii*) cod catch per unit effort in kilograms per hour (CCPUE); (*iv*) median length of species catch in centimetres (MED). Table 2 summarizes the distribution of these variables over the entire data set. The median length variable is species specific, in that the median length of the haddock catch is used to model haddock DL_{50} and so on. The CPUE and median length of the species catch are clearly measures of abundance and size of the species catch. The CPUEs of the other two gadoids are used to explore whether "species interactions" influence discarding. Biomass was estimated from the combined length distribution of discards and landings, using monthly length–weight relationships (Coull et al. 1989). Logarithms were taken to reduce the skewness of the CPUE distributions, with 0.5 added to each observation to allow for zero values (i.e., when the other two gadoids were not caught in the trip).

Stratification variables

These are the variables used to stratify sampling in the Scottish discards programme, with the addition of landing harbour: (*i*) gear

Fig. 3. Box and whisker plots of the estimated DL_{50}s, by species, excluding trips from *Nephrops* trawlers.

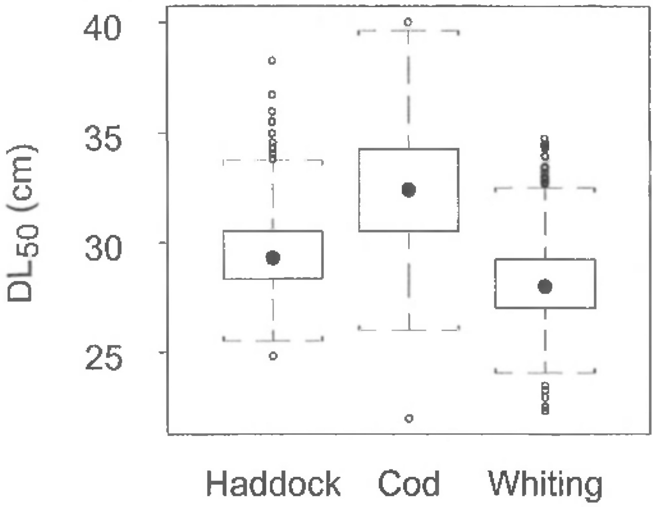


Table 2. Median and quartiles of each catch explanatory variable over the entire data set.

Variable	First quartile	Median	Third quartile
Haddock CPUE (kg·h^{-1})	6.6	10.8	16.3
Cod CPUE (kg·h^{-1})	3.0	5.6	9.0
Whiting CPUE (kg·h^{-1})	2.8	5.6	10.4
Haddock median length (cm)	26.2	29.1	31.3
Cod median length (cm)	32.2	36.2	42.3
Whiting median length (cm)	25.5	28.1	30.3

(see Table 1), (*ii*) area (see Fig. 1), (*iii*) quarter of year; and (*iv*) harbour. Note that all these variables are treated as categorical.

Annual variables

In addition to treating year as a variable in its own right, there are many variables that change only annually or every few years. These mainly relate to annually assessed biological parameters of the stocks (e.g., year-class strength, stock biomass, etc.) and to the prevailling management measures in the North Sea, i.e., minimum landing size (MLS), nominal mesh size (NMS), and quotas. MLS increased once within the study period, in 1979 for whiting (from 25 to 27 cm), and in 1989 for haddock and cod (from 27 to 30 cm and from 30 to 35 cm, respectively). NMS regulations were modified several times within the study period; the nominal size of meshes in the codend was standardized to 80 mm in 1980 and then increased to 85, 90, and 100 mm in 1987, 1989, and 1991 respectively.

It is obvious how changes in MLS may affect discarding decisions. Changes in NMS could affect discarding through changes in the size distribution of the catch; stock biomass and year-class strength through changes in the availability of resources and changing market conditions (Crean and Symes 1994); and quotas by limiting the biomass that can reach the market (Pikitch 1991). A summary of the biological variables related to the assessment of the North Sea gadoid stocks (e.g., spawning stock biomass and year-class strength) can be found in ICES (1996). Hislop (1996) discusses changes in the North Sea gadoid stocks within the study period, and Symes (1992) describes recent changes in the management regime for the North Sea demersal fisheries.

Unfortunately, having many annual variables presents modelling difficulties since, with 19 years' data, there are only 18 degrees of freedom available for investigating annual effects. To avoid problems of confounding and overfitting, we first use only year to explore temporal trends in discarding. We then relate significant year effects to other annual variables for a clearer biological interpretation.

Modelling DL_{50}

Our original intention was to use generalized additive models (GAMs: Hastie and Tibshirani 1990) to model DL_{50} for each species across the North Sea. GAMs generalize traditional regression techniques by relating the response variable to arbitrary, smooth functions of the explanatory variables. They are a particularly useful modelling tool, because they accommodate relationships of many different shapes, allowing the data to determine, to a large extent, the most suitable shape to be used. GAMs are being increasingly used in a fisheries context; see, for example, Swartzman et al. (1994) and Borchers et al. (1997). However, exploratory GAM fits revealed highly significant interactions between the explanatory variables, notably involving either area or gear. Since GAM software is not sufficiently developed to deal easily with such interactions, an alternative approach was required.

Our solution is to use two different regression techniques that examine the data from different directions. First, we use regression trees (Breiman et al. 1984; Clark and Pregibon 1993) as an exploratory tool to identify broad patterns in discarding across the North Sea. Regression trees are particularly suited to modelling interactions and dealing with a mixture of continuous and categorical explanatory variables (Venables and Ripley 1994). They operate by recursively splitting the data into homogeneous subsets (two at a time). Each split is determined by the value of an explanatory variable, with the data "below" the splitting value going into one group and the data "above" going into the other. The splitting point is chosen to minimize the within-group variance of the response variable in the two subsets.

We fitted a tree to the DL_{50} of each species using the explanatory variables described above:

$$DL_{50} \sim \text{Year} + \text{Area} + \text{Gear} + \text{Quarter} + \text{Harbour} + \text{HCPUE} + \text{CCPUE} + \text{WCPUE} + \text{Median}.$$

The trees were initially fitted with no constraints on the size of the fitted model, leading to some overfitting. The optimal tree size was then evaluated by cross-validation (Efron and Tibshirani 1993). The results of a regression tree must, in some sense, be regarded as exploratory, since there are no formal tests of significance involved in model selection. However, cross-validation gives the tree with the smallest estimated prediction error.

Second, we obtain more detailed insight into discarding patterns by fitting separate GAMs to subsets of the data, corresponding to each combination of area and gear. Using GAMs in this way avoids the problem of modelling the interactions involving area or gear. The drawback is that there is no formal way of assessing area and gear effects, other than by a qualitative inspection of the fitted models across areas and gears. However, we feel that combining the detailed GAM results with the "overview" provided by the regression trees allows us to built a cohesive picture of discarding patterns in the North Sea.

For each area and gear combination, we fitted a "full" model that included all explanatory variables (other than area and gear):

$$DL_{50} \sim \text{Year} + \text{Quarter} + \text{Harbour} + \text{HCPUE} + \text{CCPUE} + \text{WCPUE} + \text{Median}.$$

In this model, catch variables were fitted as smoothers with 4 degrees of freedom (df) and year was fitted as a categorical variable to allow DL_{50}s to vary freely between years. Normally distributed errors were assumed. The full model was then simplified using a stepwise selection procedure (Draper and Smith 1981), in which the catch variables were also considered as linear effects (1 df), and year as a smooth effect on 5, 3, and 1 df. Fewer degrees of freedom were allowed for year in area and gear combinations with less than 15 years of sampling. Model selection was based on Akaike's information criterion

(AIC). However, in stepwise regression, terms nonsignificant at the 5% level may not be removed by AIC (e.g., Buckland et al. 1992). To overcome this, we did a backward search on the final model, removing all terms nonsignificant in an F test at the 5% level. The adequacy of the selected model was investigated by residual plots. Finally, we tried to replace any significant year effect by the other biological and regulatory annual variables.

Results

Figures 4*a*–4*c* shows the selected regression trees of haddock, cod, and whiting, respectively. The haddock and cod trees are very similar. Both show a strong spatial separation within the North Sea, with smaller DL_{50}s in Moray Firth and Buchan. This is equivalent to an inshore–offshore grouping, since Moray Firth and Buchan are coastal areas, easily approached from harbours in eastern and northern Scotland (Fig. 1). Both trees also show an increase in DL_{50} in inshore areas around 1989. This coincides with the only increase in the MLS of these species during the study period, although NMS also increased in the same year (from 85 to 90 mm). The haddock tree also shows that before 1989, vessels fishing inshore and landing in small harbours had smaller DL_{50}s than those landing in large harbours. Further, in offshore areas, haddock DL_{50} increases when larger haddock are caught. Possible explanations for these findings are discussed later.

The most important variable in the whiting tree is the median length of the whiting catch, with larger DL_{50}s when larger whiting are caught. There is also a temporal effect, with an increase in DL_{50} around 1979. Again, this coincides with the only increase in whiting MLS during the study period. After 1979, an area separation appears, with smaller DL_{50}s in Buchan and Shetland. Note that gear does not appear in any tree, which suggests that any gear effect can only be of secondary importance compared with those effects in the trees.

Tables 3–5 show the selected GAMs for each area and gear combination. Year is the most important explanatory variable, being highly significant in most data sets. The fitted temporal patterns are plotted in Figs. 5*a*–5*c* and show that DL_{50} generally changes in a smooth, linear, or stepwise manner over time. The temporal trends differ between areas and gears, demonstrating some of the interactions discussed earlier (i.e., between area, gear, and year). However, for haddock (Fig. 5*a*), common features can be observed in many data sets; DL_{50}s often show an increase from the late 1970s to the early 1980s, a peak around 1982–1983, a decrease during the rest of the 1980s, and another increase from 1989 onwards. The temporal patterns in cod (Fig. 5*b*) are simpler than in haddock and also show common features across data sets, with changes in DL_{50} often being adequately explained by MLS. For whiting (Fig. 5*c*), the temporal patterns are more ambiguous and suggest gear-dependent temporal trends. The most consistent is for seine (the gear most thoroughly sampled throughout the study), where the increase of MLS in 1979 generally coincides with an increase in DL_{50}.

For haddock and cod, the catch and stratification variables were sometimes significant (Tables 3 and 4), but these effects were not consistent either across areas (within gears), or across gears (within areas). Conversely, the whiting GAMs show an interesting relationship between DL_{50} and the catch variables. In offshore areas, there are strong relationships with the catch

Fig. 4. Regression trees for DL_{50}: (*a*) haddock; (*b*) cod; (*c*) whiting. Values in boxes are the fitted DL_{50}s at each level of the tree partition. Variables given in boldface are those significant for the ensuing binary partition. The levels of the significant variable that lead to different branches of the tree are indicated at each splitting point. For example, the first partition in the haddock tree is according to area. Trips in Buchan and Moray Firth have a fitted DL_{50} of 28.6 cm and trips in the remaining areas have a fitted DL_{50} of 30.4 cm.

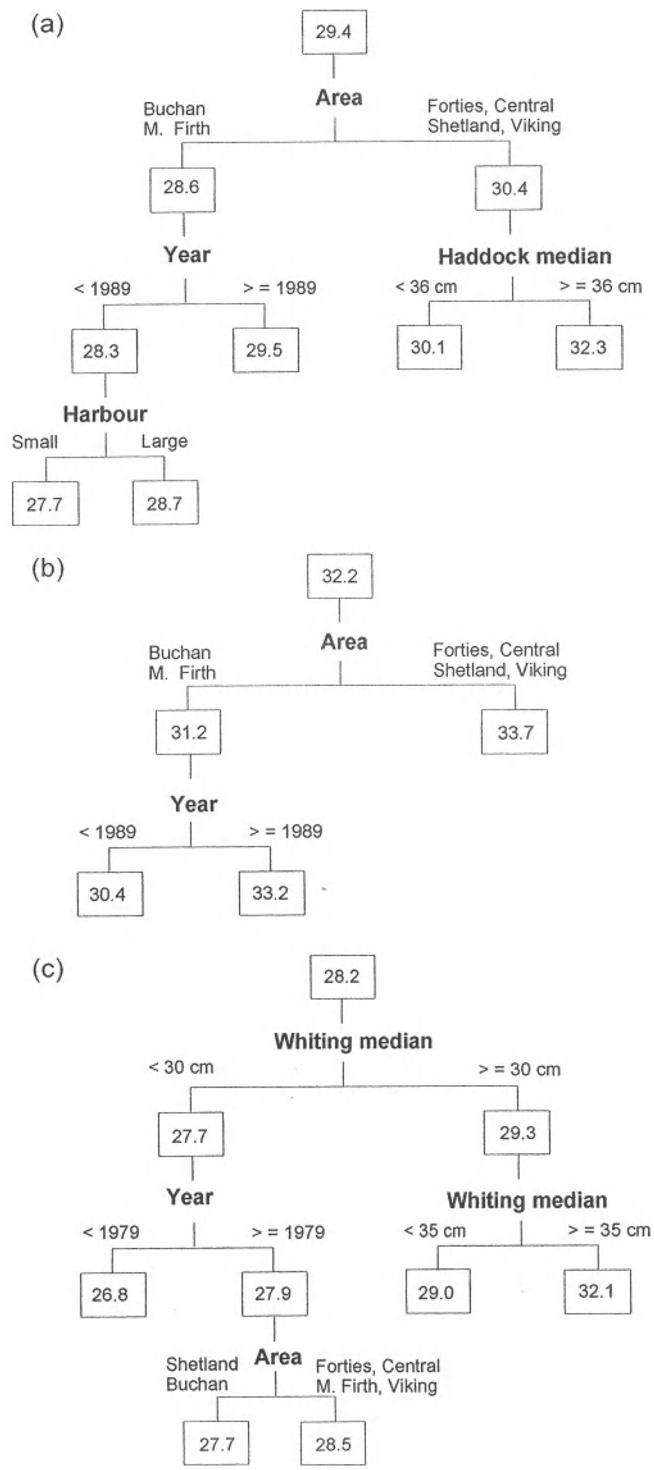


Table 3. Selected model, residual variance (s^2), and proportion of explained variance (R^2) for GAMs fitted to haddock DL_{50} by area and gear.

		Selected model				
Area	Gear	Annual	Stratification	Catch	s^2	R^2
Shetland	Heavy	Year (3)	—	CCPUE +**HMED** (4)	1.1	0.74
	Seine	**Year** (5)	—	WCPUE (4)	2.1	0.43
	Light	—	—	CCPUE (4) + HCPUE + WCPUE	0.7	0.70
	Pair	Year	—	—	1.5	0.22
Viking	Seine	**Year** (5)	—	WCPUE + **HMED**	2.1	0.61
Forties	Seine	Year (5)	—	—	2.4	0.36
Central	Seine	Year	**Harbour**	CCPUE + **HCPUE** + HMED	1.1	0.61
Moray Firth	Seine	**Year** (5)	—	—	1.2	0.29
	Light	**Year***	—	—	0.4	0.81
	Nephrops	—	Harbour	CCPUE (4) + WCPUE (4)	1.3	0.44
Buchan	Heavy	Year*	—	HCPUE	1.3	0.59
	Seine	**Year** (5)	Harbour	HCPUE (4) + **HMED** (4)	0.6	0.71
	Light	**Year***	**Harbour** + quarter	**HCPUE** (4) + WCPUE (4)	0.4	0.78
	Nephrops	**MLS**	**Quarter**	—	1.2	0.69
	Pair	**Year**	—	CCPUE	0.9	0.56

Note: When an explanatory variable is fitted as a smooth term, it is followed by a value in parentheses that gives the degrees of freedom of the smooth. When year is fitted as a categorical variable, this is indicated by an asterisk. Only terms significant at the 5% level or greater are shown; those significant at the 1% level are underlined; and those significant at the 0.1% level are shown in bold. CCPUE, cod CPUE; HCPUE, haddock CPUE; HMED, haddock median length; WCPUE, whiting CPUE.

Table 4. Selected model, residual variance (s^2), and proportion of explained variance (R^2) for GAMs fitted to cod DL_{50} by area and gear.

		Selected model				
Area	Gear	Annual	Stratification	Catch	s^2	R^2
Shetland	Heavy	Year (2)	—	CMED	4.3	0.31
	Seine	Year (3)	—	WCPUE	5.2	0.25
	Light	—	—	—	5.2	—
	Pair	Year	—	—	5.0	0.29
Viking	Seine	Year (3)	Quarter	—	3.2	0.38
Forties	Seine	MLS	—	—	3.4	0.11
Central	Seine	MLS	Harbour	CCPUE (4) + HCPUE	1.8	0.53
Moray Firth	Seine	MLS	—	—	4.3	0.09
	Light	—	—	—	4.9	—
	Nephrops	—	Harbour	—	11.6	0.12
Buchan	Heavy	—	—	—	3.1	—
	Seine	**MLS**	—	—	3.0	0.49
	Light	MLS	—	—	2.8	0.31
	Nephrops	**Year** (3)	Harbour	**CCPUE** (4) + HCPUE	5.5	0.63
	Pair	**MLS**	Quarter	—	1.6	0.74

Note: When an explanatory variable is fitted as a smooth term, it is followed by a value in parentheses that gives the degrees of freedom of the smooth. When year is fitted as a categorical variable, this is indicated by an asterisk. Only terms significant at the 5% level or greater are shown; those significant at the 1% level are underlined; and those significant at the 0.1% level are shown in boldface. CMED, cod median length. Other variables are as in Table 3.

variables (Table 5). When significant, DL_{50} is always positively related to haddock CPUE, cod CPUE, and the median length of the whiting catch and negatively related to whiting CPUE. In inshore areas, there are few significant catch effects. These findings are interpreted below.

Discussion

Interpretation of patterns in DL_{50}

We now piece together the GAM and regression tree results to describe discarding patterns across the North Sea. The haddock and cod trees suggest an inshore–offshore effect on discarding (Figs. 4*a* and 4*b*). This is supported by the GAMs (Figs. 5*a* and 5*b*), where the predicted DL_{50}s are larger offshore. The GAMs show a similar effect for whiting (Fig. 5*c*). However, this is not supported by the whiting tree (Fig. 4*c*), where the median length of the (whiting) catch, rather than area, has the dominant effect on DL_{50}. This can be explained by considering how the median length of the whiting catch changes with area (Fig. 6*a*). Catches in Moray Firth and

Table 5. Selected model, residual variance (s^2), and proportion of explained variance (R^2) for GAMs fitted to whiting DL_{50} by area and gear.

		Selected model				
Area	Gear	Annual	Stratification	Catch	s^2	R^2
Shetland	Heavy	—	—	**WMED**	2.3	0.34
	Seine	Year (5)	—	**HCPUE + WCPUE + WMED**	2.8	0.44
	Light	Year (3)	—	<u>WCPUE</u> + WMED	2.1	0.56
	Pair	<u>Year</u>	Quarter	<u>CCPUE</u> + HCPUE + <u>WCPUE</u>	1.4	0.79
Viking	Seine	**Year** (3)	—	<u>CCPUE</u> + <u>WMED</u>	2.4	0.62
Forties	Seine	<u>Year</u> (3)	—	—	3.3	0.23
Central	Seine	<u>MLS</u>	—	<u>CCPUE</u> + <u>HCPUE</u> + <u>WMED</u>	2.2	0.41
Moray Firth	Seine	**Year** (3)	—	HCPUE	1.4	0.58
	Light	Year	—	WCPUE	1.1	0.23
	Nephrops	Year (2)	—	<u>WMED</u> (4)	1.1	0.43
Buchan	Heavy	—	—	—	2.7	—
	Seine	**MLS**	—	WCPUE	1.4	0.13
	Light	—	—	CCPUE (4) + WMED	0.9	0.80
	Nephrops	**Year***	—	WCPUE	0.3	0.75
	Pair	<u>Year</u>	Quarter	—	0.7	0.47

Note: When an explanatory variable is fitted as a smooth term, it is followed by a value in parentheses that gives the degrees of freedom of the smooth. When year is fitted as a categorical variable, this is indicated by an asterisk. Only terms significant at the 5% level or greater are shown; those significant at the 1% level are underlined; and those significant at the 0.1% level are shown in bold. WMED, Whiting median length. Other variables are given in Table 3.

Buchan comprise smaller whiting than catches in offshore areas, so that area and median length of the catch are confounded. If we repeat the whiting regression tree excluding median length, then the inshore–offshore pattern emerges as the dominant effect. Thus, whiting DL_{50}s are greater offshore, where larger whiting tend to be caught. In fact, the median length of haddock is also related to area (Fig. 6*b*), suggesting that spatial patterns are confounded with haddock size. No such pattern is found for cod.

Table 5 suggests a further inshore–offshore difference in the discarding of whiting, since the catch variables have a large effect on whiting DL_{50} in offshore areas, but only a negligible effect inshore. In inshore areas, the median length of the whiting catch is distributed around the MLS (Fig. 6*a*), so discarding decisions are likely to be dominated by legal size considerations, rather than the composition of the catch. Offshore, whiting median length is distributed about sizes greater than the MLS, so the catch variables can become more important. In offshore areas, whiting DL_{50} tends to be positively related to the abundance of haddock and cod in the catch, and, unexpectedly, negatively related to the abundance of whiting in the catch. This can be interpreted as a shift in primary target species when whiting dominates the catch: a tight selection for the lesser valued whiting only occurs when whiting is abundant relative to the primary market targets, haddock and cod.

The GAMs show that temporal patterns in discarding can best be described by a smooth curve, a straight line, or a single step (Fig. 5). This confirms that DL_{50}s change systematically over time, rather than in response to noisy, short-term effects, such as recruitment variation. Only occasionally were the observed temporal patterns adequately explained by biological or regulatory annual variables, and this always involved MLS. Of course, this does not necessarily mean that biological and regulatory variables do not affect DL_{50}, merely that the changes in DL_{50} are more complicated that can be explained by these variables alone.

Changes in MLS offer a plausible explanation for many of the observed temporal patterns in DL_{50}. Even when MLS does not adequately explain all the temporal variation, increases in DL_{50} generally occurred around the time of MLS increases (Fig. 5). However, changes in NMS and MLS occurred at similar times. Although it is not possible to formally disentangle these two effects, there are several reasons why MLS is more likely to be the causative effect. First, NMS can only have an indirect effect on discarding decisions by altering the size distribution of the catch. Further, if NMS was the only factor to influence DL_{50}, it would have a simultaneous effect on all three species, which should lead to similar DL_{50}s across species. However, whiting DL_{50}s do not, in general, increase around 1989 (Fig. 5 c). Also, especially after 1989, the DL_{50}s of the three species are separated by several centimetres, lying close to their respective MLSs (Fig. 5).

On the other hand, for the MLS hypothesis to hold, MLS should have a similar impact across areas and gears. This is not evident in the regression trees, which suggest that the change in MLS only affected inshore areas. However, the GAM results suggest that haddock and cod DL_{50}s also increased in offshore areas around 1989 (Figs. 5*a* and 5*b*), and whiting DL_{50}s shifted in some offshore areas around 1979 (Fig. 5*c*). Before the changes in MLS, the DL_{50}s of all three species were consistently higher offshore. The shifts in MLS would therefore have been more easily accommodated offshore and, hence, might not have been identified by the regression trees.

The other temporal pattern to be explained is the increase in haddock DL_{50}s in the early 1980s and its subsequent decrease. Here, we can only speculate. The spawning stock biomass of haddock was comparatively high in the early 1980s but then reached historically low levels by the end of the decade (Hislop 1996), so DL_{50} could be related to species abundance. Also, the introduction of the Common Fisheries Policy in 1983 led to a tighter enforcement of quotas, so quota

Fig. 5. Annual DL_{50} predictions and partial residuals by area and gear: (*a*) haddock; (*b*) cod; (*c*) whiting. The dotted line is the minimum landing size. The lower two rows correspond to inshore areas and the upper two rows to offshore areas.

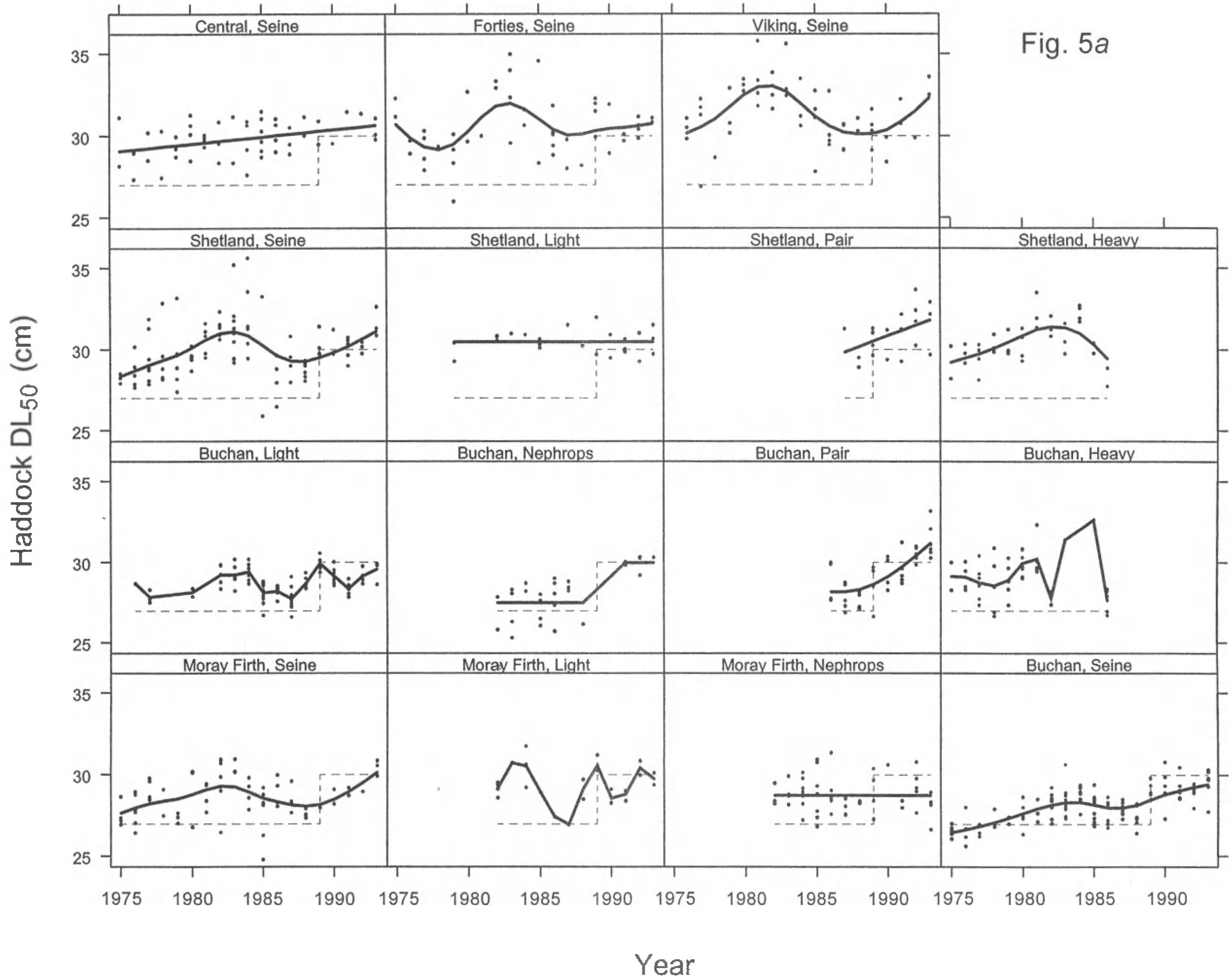


Fig. 5 (*continued*).

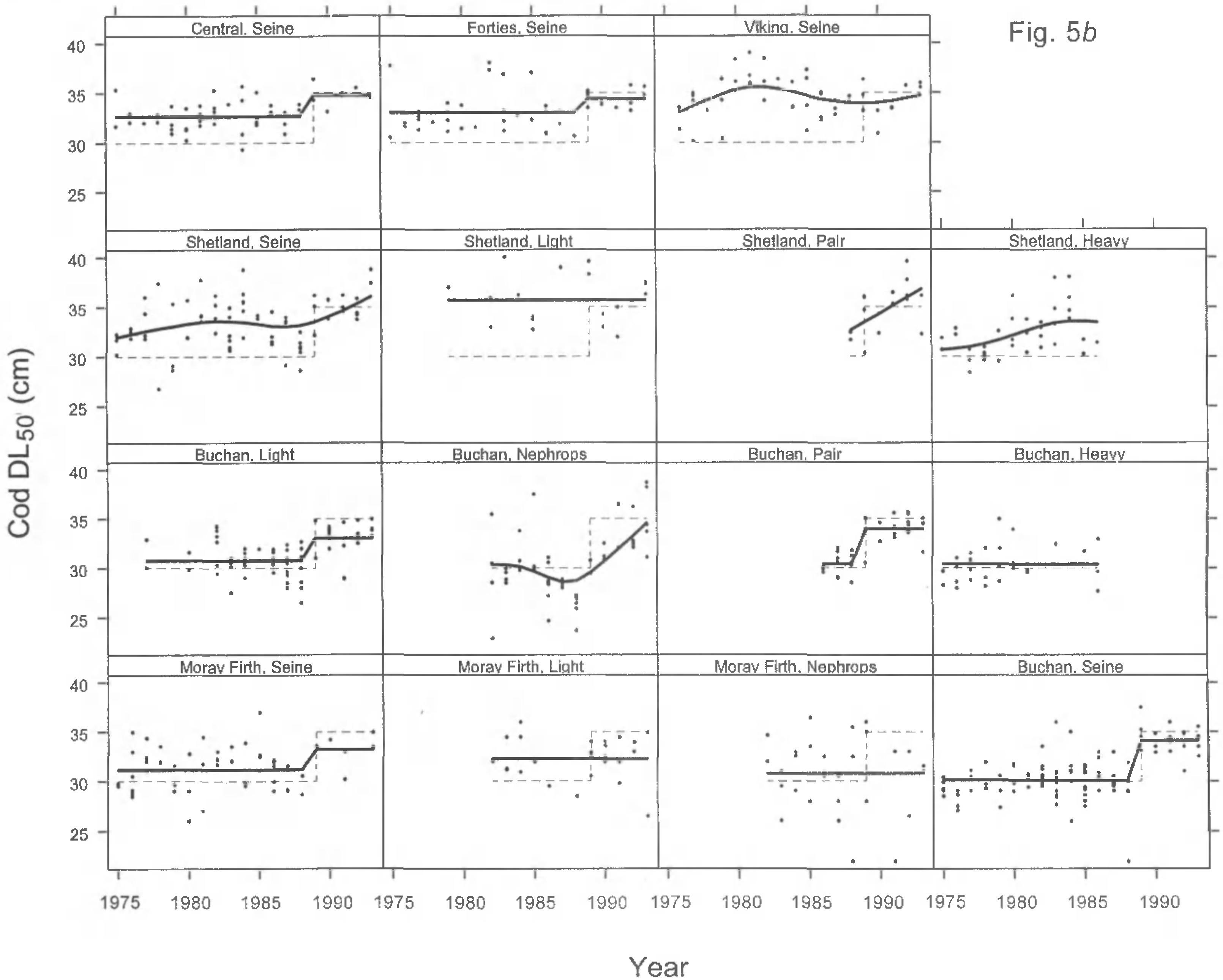
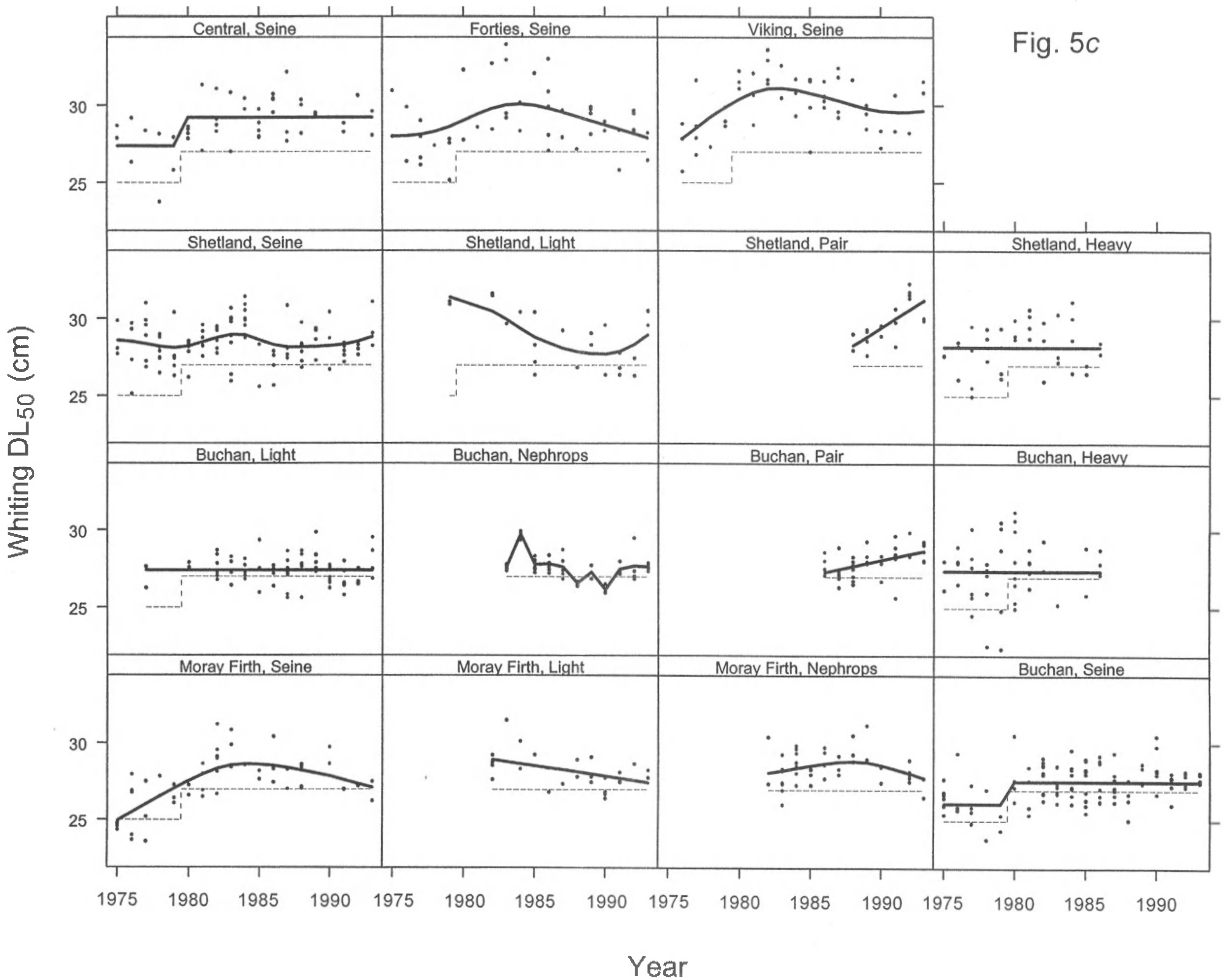


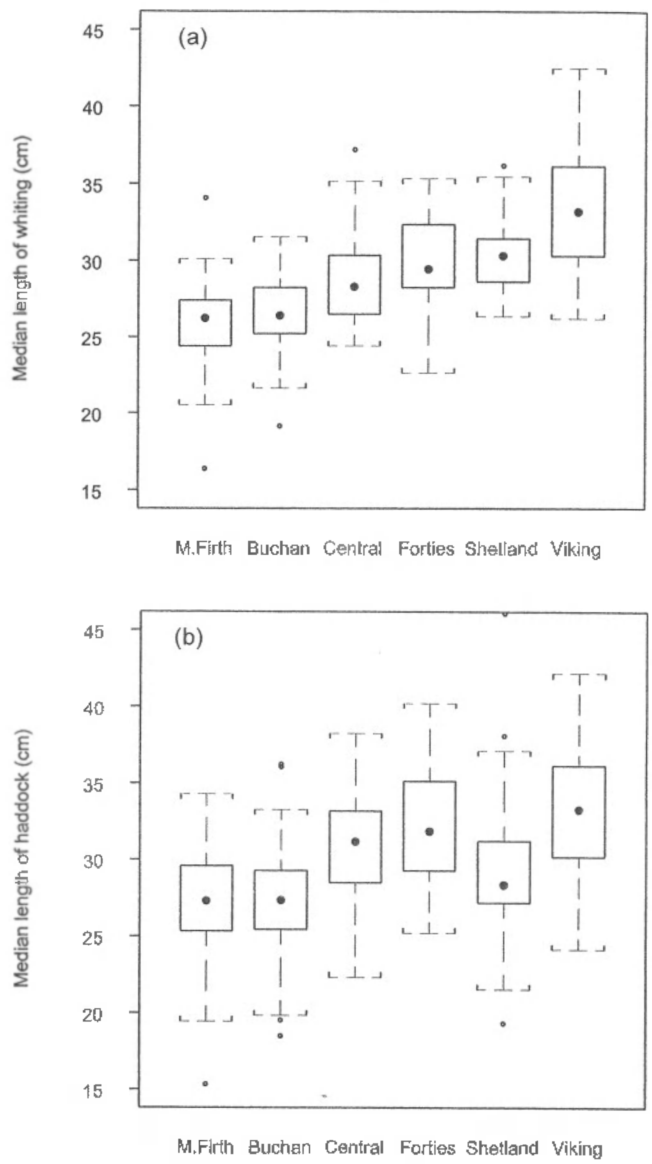
Fig. 5 (*concluded*).



pressures could have started influencing discarding decisions around this time. When quotas can be easily reached, quota pressures might cause fishers to keep only the larger, more marketable, fish (Alverson et al. 1994). Haddock DL_{50}s were highest in a period (1982–1984) when landings were close to the allocated quotas, whilst the subsequent decrease in DL_{50} corresponds to a period when landings were much lower than the quotas (ICES 1996).

The preliminary GAM fits to the whole data set revealed highly significant interactions, particularly involving area and gear. We can interpret these interactions by comparing the fitted effects for each area and gear combination in Fig. 5 and Table 5. There are clearly important interactions between area and the catch variables for whiting, since there are strong relationships between DL_{50} and the catch variables offshore and very weak relationships (if at all) inshore. The temporal trends are also area and gear specific. Here, however, once we remove the main effect of larger DL_{50}s in offshore areas, the differences in temporal patterns between areas and gears are small and have no apparent structure. Thus, we conclude that, while these interactions are statistically significant, they do not represent important biological or technological effects.

Fig. 6. Box and whisker plots of the median length of whiting (*a*) and haddock (*b*) catches in seine trips by area.



General considerations

Despite the many vessels and trips sampled to provide the data for this study, generalizations should be considered with care. The data come from a voluntary scheme where sampling is restricted to vessels willing to cooperate and with working and living space available for the scientific observer. We therefore assume that discarding on these vessels is representative of Scottish demersal vessels as a whole. We also assume that fishing practices and discarding behaviour do not change in the presence of observers. Nevertheless, the Scottish data provide one of the best opportunities to investigate discarding on a relatively large spatial and temporal scale using real data.

The most striking result of this study is the difference in discarding practices between areas, conveniently summarized by an inshore–offshore separation. This separation is, of course, artificial, since there are no regulatory differences in the management of these areas. It is difficult to see why a vessel fishing "inshore" in eastern Buchan will adopt different discarding practices from one fishing "offshore," a few miles away in western Forties (see Fig. 1). However, this type of crude binary categorization is not uncommon when describing aspects of fishers' behaviour (Smith and McKelvey 1986) and is a useful tool for highlighting alternative discarding strategies.

If we divide the Scottish demersal fleet into an inshore and offshore component, larger vessels and more enterprising skippers ("stochasts" according to Allen and McGlade 1986) are likely to fish offshore, where there is a greater proportion of desirable fish sizes in the catch (P.J. Wright, Marine Laboratory, Aberdeen, U.K., personal communication). Such vessels tend to target larger fish, which have a higher market value. Anecdotal evidence suggests that, in the earlier years, vessels fishing offshore often used nets with mesh sizes larger than the NMS, to reduce the amount of "trash" fish in the catch and, hence, the time devoted to sorting. Before 1989, this practice led to the discarding of haddock and cod much larger than the MLS. This seems to indicate typical high-grading decisions. High-grading is the behaviour where potentially marketable fish are discarded to make space for more valuable fish when total landings are limited by trip quotas or hold capacity (Alverson et al. 1994; Gillis et al. 1995*a*, 1995*b*). In Scotland, hold capacity can hardly be considered restrictive, and quotas are mainly allocated on a vessel-specific monthly basis (Symes 1992). Nevertheless, it is plausible that a combination of quota pressures (albeit not imposed on a trip level) and financial considerations make fishers selective in what they keep for the market. After 1989, MLS considerations have become more important, with haddock and, especially cod, discarded close to the MLS.

Inshore areas are associated with smaller fish, but safer fishing conditions and reduced steaming time. Fishers less prepared to take risks ("cartesians" according to Allen and McGlade 1986) or with smaller vessels are therefore likely to fish closer to the home port. In these situations the scarcity of high-quality fish obliges fishers to land virtually everything above the MLS. Indeed, the selection is often so tight that measuring sticks are employed to compare fish with the imposed MLS. Thus, inshore fishers are mainly constrained by MLS, which has been shown to be a powerful enforcement tool generating an immediate reaction of the fishers. Note, however, that, despite the obvious effort to conform with the new regulation, even several years after the change in MLS for haddock and cod, many inshore gears still had average DL_{50}s below the legal size (Figs. 5*a* and 5*b*).

Whiting discarding strategies differ from those for haddock and cod. Again there is an inshore–offshore separation, with discarding inshore being mainly determined by the MLS. However, unlike haddock and cod, the increase in MLS was relatively easily accommodated by the fishers. Offshore, the composition of the catch has the greatest effect on discarding. A high-grading mechanism based on the threats of quota management is less likely for whiting, since landings are usually well below the allocated quotas (ICES 1996). A more plausible explanation is that whiting, having smaller commercial value than haddock and cod, is usually a secondary target when the other two species are abundant in the catch. In such cases, whiting are only kept at sizes comparable with those of haddock and cod, above the current whiting MLS. When whiting dominate the catch, fishers seem to switch target species and land most whiting of legal size. It might be possible to explore this idea further, by using optimal foraging theory models to investigate whether changes in the relative abundance of prey (catch of haddock, whiting, and cod) can adequately explain the observed selection strategy of the predator (fisher).

In conclusion, we have shown that data from routine discards sampling programmes can also address issues not directly related to the estimation of total discards. The identification of specific discarding practices (e.g., differences between the inshore and offshore sector, reactions to MLS changes), can help to evaluate the effectiveness and social implications of future management measures designed to curb discarding. Further, annual estimates of DL_{50} can be incorporated in assessment models for stocks where direct monitoring of discards is not available (e.g., Chen and Gordon 1997). Finally, our observation of illegal practices in sampled trips (landing below MLS) supports earlier views (Cotter 1995) that the reliability of discards sampling programmes depend on the development of a raport with the fishers, rather than on enforcement.

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