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# Short communication

# Modelling discard ogives from Irish demersal fisheries

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Annual discard ogives were estimated using generalized additive models (GAMs) for four demersal fish species: whiting, haddock, megrim, and plaice. The analysis was based on data collected on board commercial vessels and at Irish fishing ports from 1995 to 2003. For all species the most important factors influencing annual discard ogives were fleet (combination of gear, fishing ground, and targeted species), mean length of the catch and year, and, for megrim, also minimum landing size. The length at which fish are discarded has increased since 2000 for haddock, whiting, and plaice. In contrast, discarded length has decreased for megrim, accompanying a reduction in minimum landing size in 2000.



Keywords: demersal fisheries, discard ogives, GAM, haddock, megrim, plaice, whiting.

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## Introduction

Discarding part of the catch at sea is usual in commercial fisheries. This is because fishing gears are generally not fully selective for the target species, and they therefore catch some species, sizes, or condition (e.g. damaged) with low market value. A substantial proportion of the commercial catch from the waters around Ireland is discarded (Borges *et al.*, 2005a). Such discarding contributes substantially to the mortality caused by fishing, yet the fisheries statistics upon which fisheries management decisions are based there do not include adequate estimates of the quantities of fish discarded at sea (ICES, 2005, 2006). Unfortunately, direct on-board estimation of discards by scientific observers is costly, and such programmes have only recently been established in many fisheries. Available data on discarding are consequently often patchy and of poor resolution.

The application of modelling approaches to discard data provides a means of more fully extracting the information content of available data. Such modelling approaches can also be used to minimize "noise" in the available data while still presenting some measure of precision (confidence intervals). Moreover, discard models may be used to predict discards in unsampled strata or into the future for partially discarded length/age classes.

Discarding can be expressed as the probability of an individual being discarded at a given length. For commercial species, this probability generally decreases with increasing length and is zero after a certain length, because the specimen will eventually attain a commercial size and will be landed. Such data will have an S-shape curve and have previously been described by logistic function ogives (Stratoudakis *et al.*, 1998; Rochet *et al.*, 2002; Palsson, 2003; Machias *et al.*, 2004; Rochet and Trenkel, 2005), hereafter called a discard ogive. While estimating these species-specific curves, one can determine the effect of certain variables (e.g. year, area, gear) on the probability of discarding, because discards are highly variable between areas (Stratoudakis *et al.*, 1999), depths (Allain *et al.*, 2003), gears, and years (Borges *et al.*, 2005a). Previous modelling of discards has generally been restricted to describing the relationship between discard rates and explanatory variables, without considering the age or

 

## Results

The GAMs show that length, fleet, year, and MCL had an effect on the proportion of fish discarded annually in all four species (Table 1). Different fleets exhibit different discard behaviour, and therefore different discard ogives. Furthermore, the change in discard length with year follows a specific pattern: a decrease until 1999–2000 and an increase thereafter for all species, except for megrim, where there is a steady decline in discard length with year. The mean catch length (MCL) is negatively related to discard probability, i.e. the larger the mean length of the catch, the lower the level of discarding (Figure 2), so the discarded length decreases (ogives shift to the left). The non-linear effect of year is shown in Figures 3–6 by a shift of the discard ogives (to the right with increasing discards) and therefore by an increase in DL50 (the length at which 50% fish are discarded), and also by the different distance between curves (and DL50 values), which is relative to the level of each year effect. As a consequence, several annual discard ogives are closer together (similar DL50), or more isolated than others. The combined effect of MCL and year is also reflected in the distance between annual ogives. In fleets where MCL is decreasing and the discard probability is increasing with year, the predicted discard ogives are shifted to the right and the distance between them is larger (higher DL50) than where there is no MCL effect in the model. This is the case for the haddock and whiting fleets, the opposite is true for megrim. For plaice, however, MCL has the opposite effect of year, and the resulting discard ogives are still shifted to the right (year effect), but the distance between ogives is smaller than with no MCL effect. The partial plots of the smoother applied to length (not presented) were similar between species, and they did not show the substantial departures from linearity as the smoothers applied to year and MCL. Therefore the resulting discard ogives appeared to be symmetrical with respect to length, and they did not differ substantially in the majority of fleets and species studied. Recruitment was a highly significant explanatory variable in the GAMs for haddock ($p < 0.001$), borderline significant for whiting and megrim ($p < 0.05$), but not significant for plaice ($p > 0.1$). However, because some stocks are not analytically assessed (e.g. plaice in VIIj), have missing assessment years (e.g. haddock in 2003), and also because ICES assessments are carried out per stock as opposed to fleet and stock, introducing this variable in the models resulted in a data loss of around 37% for all species, except for plaice where data loss reached 62%. In view of these limitations, recruitment was excluded from the final models for all species. Finally, visual inspection of the deviance residual plots did not show major patterns or trends for any of the GAMs estimated.

Considering each species separately, haddock shows a change in the shape of the discard ogives with time: the "inclination" of the curve is less pronounced in otter trawlers operating in ICES Divisions VIb (Rockall Bank) and VIIb (West of Achill). These two fishing fleets also discard considerably larger haddock than the other fleets, particularly at lengths above MLS (Figures 3 and 4). Whiting were discarded at markedly longer lengths than the established MLS (23 cm) before 2000. Whiting also have a greater probability of being discarded by beam trawlers operating in the Irish Sea than by otter trawlers targeting *Nephrops* (data not presented). Finally, both species showed an increase in discarding since 2000, particularly in 2003 for whiting. There is also a significant effect of year in beam trawlers for both species. However, this effect is borderline significant and highly variable because of missing data in recent years, so the interaction term between fleet and year was excluded in the final model.

Megrim was the only species where the change in minimum landing size (MLS) explained a significant proportion of the variability in discard probability. When MLS was introduced to the GAM, the drop in the discard probability in 1999–2000 in the smoother applied to year was no longer observed, and the V-shaped curve (similar to those obtained for the other species) was substituted by a decreasing trend (Figure 2). Discard ogives followed the decrease in the MLS only in two fleets: otter trawlers operating on the Rockall Bank and West of Achill. In all other fleets, although there was a decrease in discarded length since

*Table 1. Generalized additive models estimated per species between 1995 and 2003. Fleets are defined by the gear used (otter trawl, beam trawl, and "Scottish seine"), area visited (ICES Division and fishing ground), and targeted species (Nephrops norvegicus). MCL is the mean length of the catch and MLS is minimum landing size.*

| Species | Number of observations | Generalized additive models estimated |
|---|---|---|
| Haddock | 1 299 | logit(discard probability) = const. + $s$(length, 3) + fleet + $s$(year, 4) + $s$(MCL, 4) |
| Whiting | 1 282 | logit(discard probability) = const. + $s$(length, 3) + fleet + $s$(year, 4) + $s$(MCL, 4) + fleet × $s$(MCL, 4) |
| Megrim | 1 028 | logit(discard probability) = const. + $s$(length, 4) + fleet + $s$(MCL, 4) + $s$(year, 4) + MLS + fleet × MLS |
| Plaice | 756 | logit(discard probability) = const. + $s$(length, 4) + $s$(MCL, 4) + $s$(year, 4) + fleet + fleet × $s$(year, 4) |

Note: All parameters and models were significant at a 1% level. $s(X, Y)$ denotes a smooth function applied to explanatory variable $X$ with $Y$ degrees of freedom.

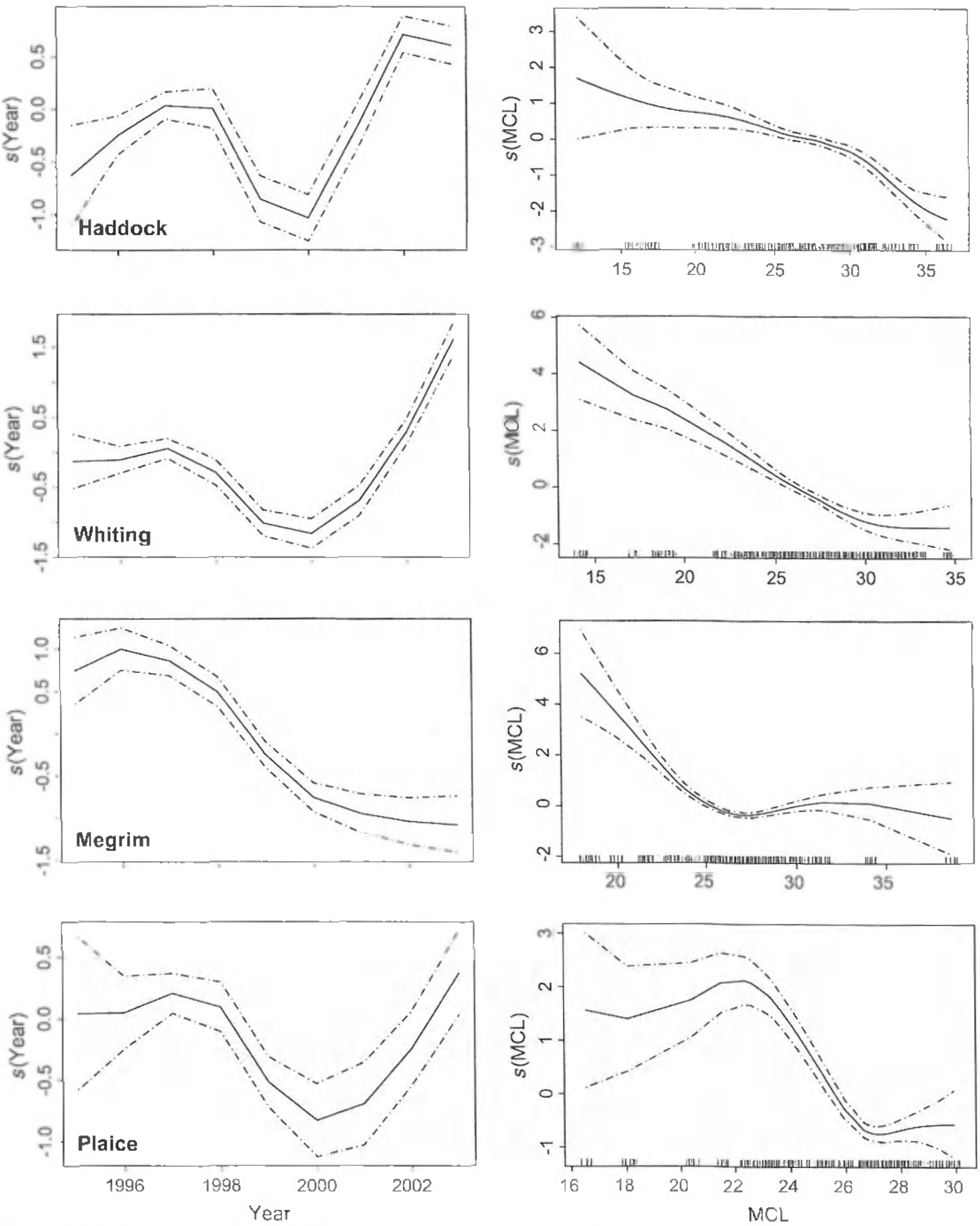


Figure 2. Partial plot of the smoother (solid line) applied to year and to mean catch length (MCL) of the generalized additive model, estimated by species and 95% confidence limit (dotted line). Vertical bars along the *x*-axis indicate the lengths sampled.

2000, there was no apparent change with MLS, except for otter trawlers operating on the Porcupine Bank. In contrast, in that fleet, there is an apparent increase in discarding with a reduction in MLS. Megrim was also retained at significantly smaller lengths by Scottish seiners than by any other fleet studied (Figures 5 and 6). Plaice shows a significant year effect, particularly in otter trawlers fishing for *Nephrops* in VIIg. Discarding increased after 2000 in all fleets, except for otter trawlers targeting *Nephrops* in VIIg. Plaice is also discarded extensively at lengths above MLS by the fleets operating in the Irish Sea and by Scottish seiners (data not presented).

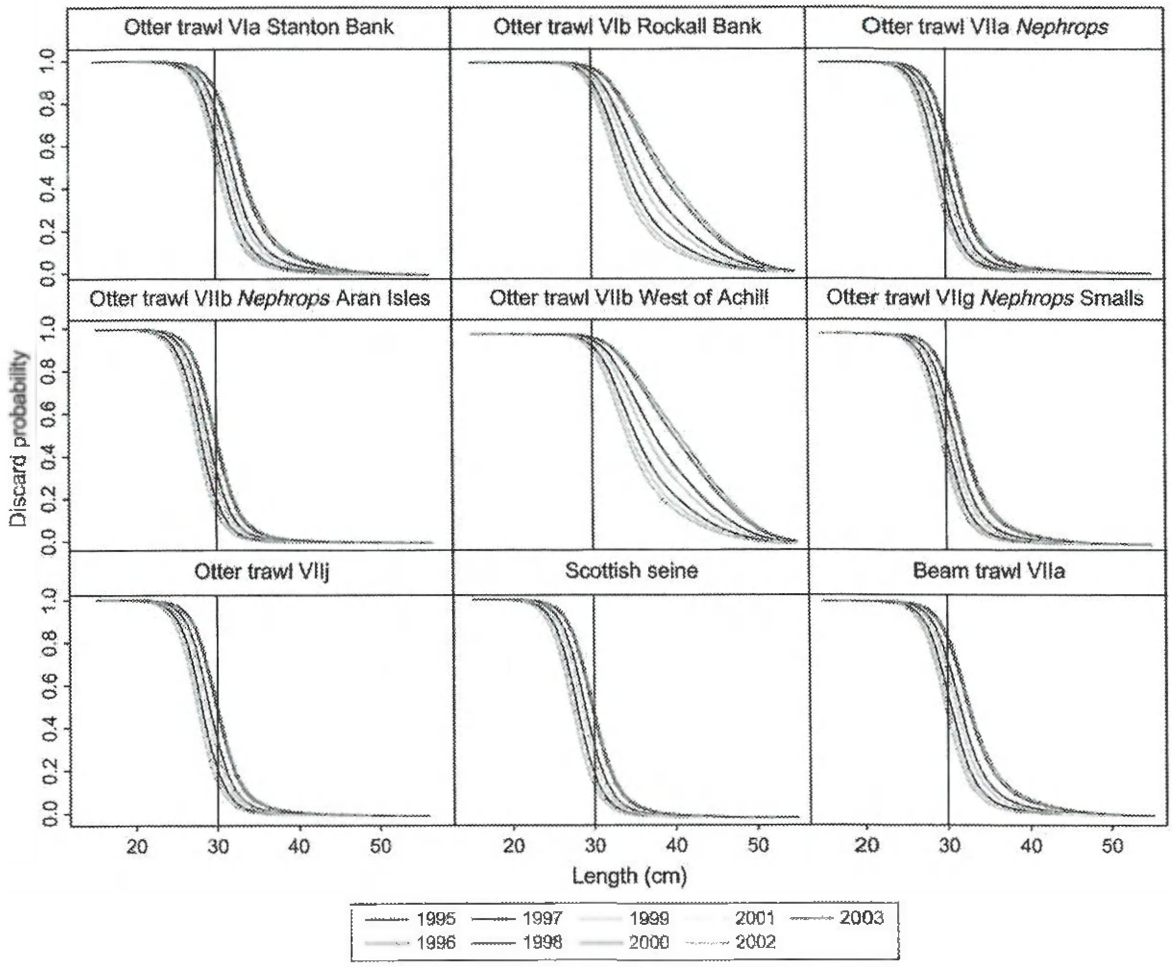


Figure 3. Predicted discard ogives based on the generalized additive model estimated of discard probability vs. length, fleet, year, and MCL for haddock. Minimum landing size (MLS) is indicated by a vertical line.

## Discussion

The fact that different fleets have different discarding practices is a result also found by Stratoudakis *et al.* (1998) and Rochet *et al.* (2002). A combination of factors such as differing market forces and fishing grounds, even in fleets with common targeted species and gear, is likely to influence fishers' behaviour and consequently to change the resulting discard ogives. These findings underline the importance of fleet-specific discard estimation to gaining a proper understanding of discard practices within fisheries.

In presenting annual discard ogives, we intended to identify significant year-on-year variations in discard practices. Stock assessments in our study area operate on an annual time-step, so require information on sources of mortality to be presented on an annual basis. We also aimed to relate observed interannual variability in discard practices to annual variables such as quotas and recruitment. However, the recruitment estimates used in the models had no significant effect (except in the case of haddock, where discards increased with recruitment). The lack of an effect is probably due to the fact that recruitment estimates used as inputs to the GAMs were drawn from stock assessments that generally consider landings only (rather than total catch). Moreover, the stock assessments are calculated from the international landings of all fleets on a stock-by-stock basis rather than by national fleets. Application of recruitment estimates from such assessments to our analysis may therefore be inappropriate. An alternative approach to using recruitment estimates from such assessments would be to use survey estimates of recruitment directly. Unfortunately, survey data are not available for the time-series at the level of disaggregation required for consistency with the discard data being modelled.

Official landings and annual quotas were initially considered in the models, but were subsequently excluded. The behaviour and utility of these variables is also questionable. Once Total Allowable Catches (TACs) are agreed at an EU

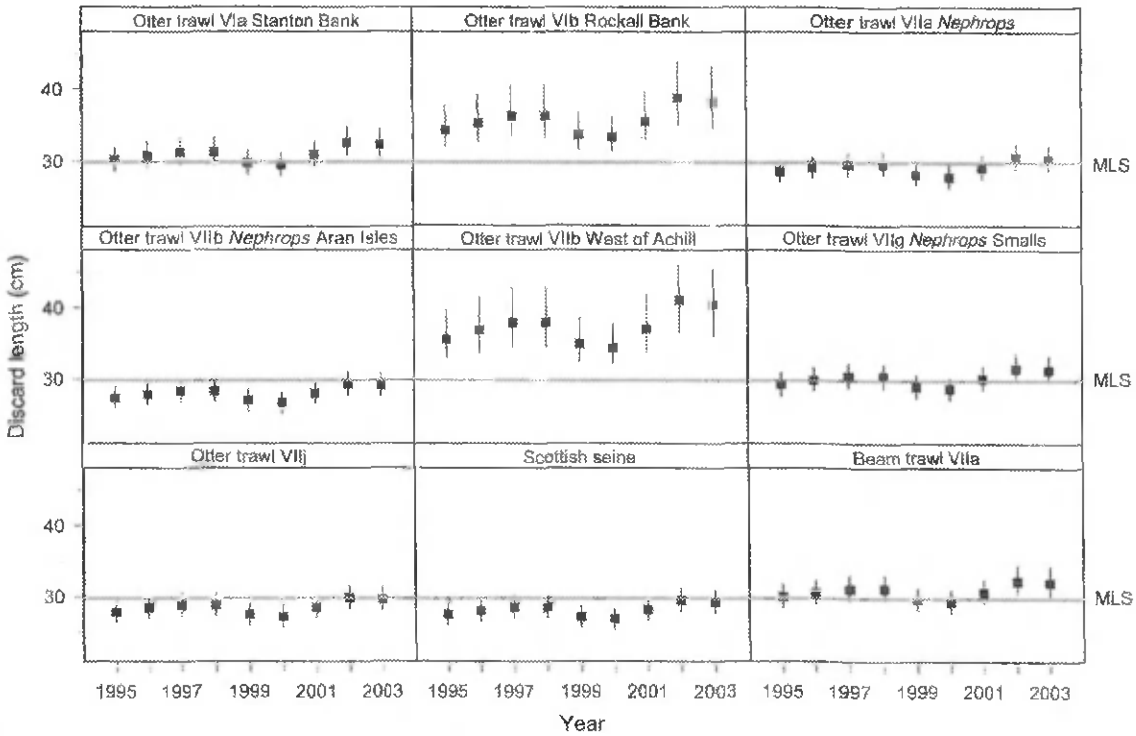


Figure 4. Predicted DL25, DL50, and DL75 (the length at which 25%, 50%, and 75% fish are discarded, respectively) based on the generalized additive model estimated of discard probability vs. length, fleet, year, and MCL for haddock. Lines represent the DL25 and DL75; squares represent the DL50. Minimum landing size (MLS) is indicated by a horizontal line.

level, national governments undertake extensive quota trading for particular stocks, and may continue to trade quota throughout the fishing year. Determining the final level of quota available to particular fisheries and fleets is therefore not a trivial task. Furthermore, allocation of national quotas by national governments to Fish Producer Organizations (and indirectly to fleets) is done in a way that may make quotas restrictive for some fleets, yet unrestrictive for others. Most importantly, for many of the stocks concerned, decreases in TAC have not restricted landings. The prevalence of misreporting has seriously undermined the veracity of reported landings statistics (ICES, 2006).

Our finding that fishers retained smaller fish when the mean length of the catch was larger was initially surprising. However, this may be explained by considering the behaviour of fishers. For fish of "intermediate" length close to, but above, MLS (say 23 cm), a crew member sorting the catch may be in doubt whether or not to discard. When a catch is predominantly of small fish, the probability of a 23 cm fish being discarded is high because fishers will be less likely to pick it out of a total catch which is considered to be small in size. Conversely, the same 23 cm fish in a catch of mainly large fish will have a lesser probability of being discarded because it can be landed mixed with larger fish.

The increase in length discarded observed for all four species in recent years may also have resulted from the evolution of the market and the influence of management measures. Moreover, increasingly stringent restrictions on landings (as during the study period) will probably alter behaviour towards fishing practices that seek to increase the value of a limited weight of catch, i.e. highgrading. Highgrading has also been reported by Stratoudakis *et al.* (1998) for haddock and whiting in offshore fleets in the North Sea. The results from the discard ogives obtained here for haddock discarded by otter trawlers operating at the Rockall Bank and West of Achill and for megrim discarded at the Porcupine Bank are consistent with highgrading. The increased levels of discarding of haddock well above the MLS in 2002 and 2003 at Rockall and West of Achill suggest other changes in discarding behaviour in recent years. A concurrent increase in targeting megrim may have induced this change, such that only haddock in best condition are retained for landing. Such factors are likely to be most pronounced on the longer trips undertaken to these grounds, and particularly for species such as haddock which keep relatively poorly. Haddock of all sizes caught early on a long trip would be expected to have a greater discard rate than those caught later in the trip. Nevertheless, in the three fleets mentioned previously, the possibility that the results may be the product of a misfit of the models estimated, owing to a lack of data in recent years, cannot be excluded.

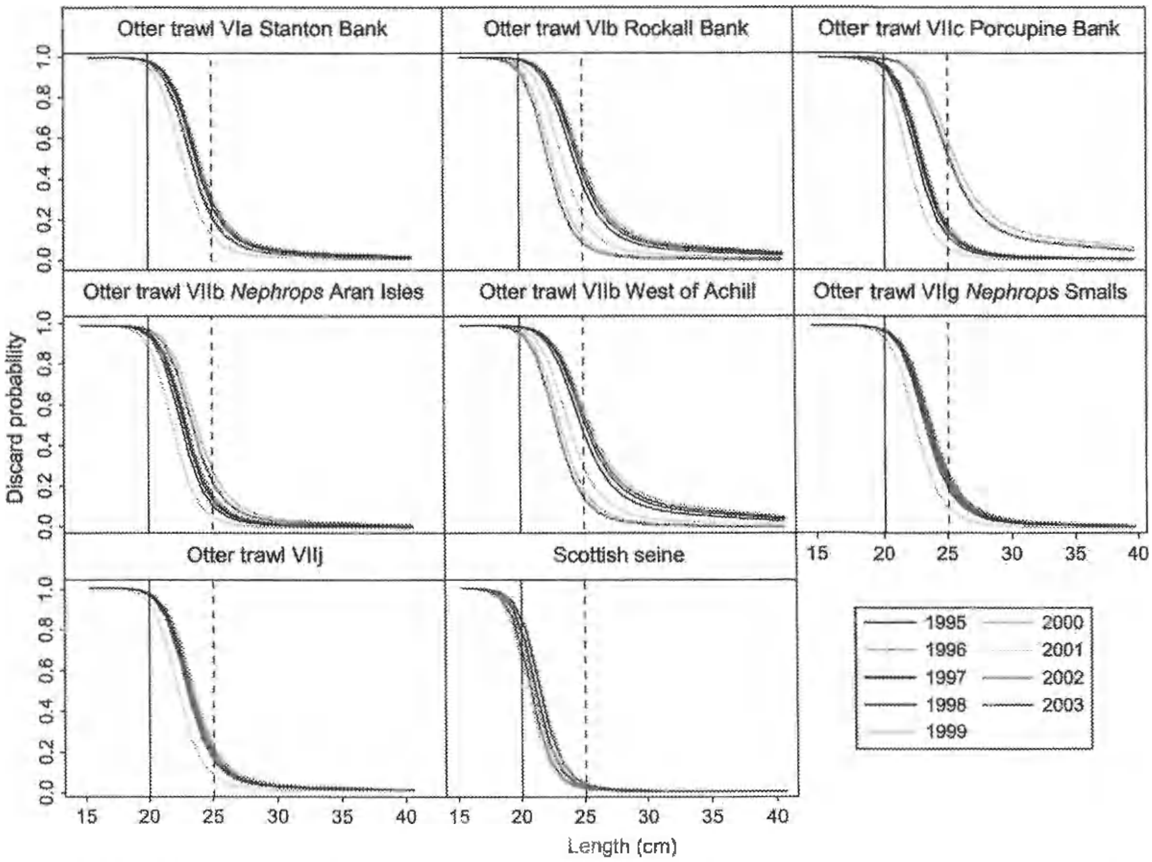


Figure 5. Predicted discard ogives based on the generalized additive model estimated of discard probability vs. length, fleet, MCL, year, MLS, and fleet × MLS interaction for megrim. Minimum landing size is indicated by a dotted line (prior to 2000) and by a solid line (for 2000 and subsequent years).

The effect of minimum landing size is, to some extent, hidden by the substantial year effect observed for the three species for which MLS was changed. MLS significantly affected megrim discards, but the effect was variable between fleets. Discarding at lengths above MLS has also been observed by Rochet *et al.* (2002) for the four species studied. In contrast, Stratoudakis *et al.* (1998) reported an immediate increase in discarding with an increase in MLS for haddock and whiting, and a systematic change over time in DL50 (the length at which 50% fish are discarded). In our study the decrease in MLS for plaice did not overcome the increase in discarded length observed with year, except for otter trawlers fishing for *Nephrops* in VIIg Smalls. As mentioned previously, estimates of discarding are not included in the assessment of this stock. There are concerns that non-inclusion of discard data represents a major deficiency in the assessment, particularly if there have been changes in discard practices over time (ICES, 2004b). Our results indicate that these concerns are well founded: a clear trend in discard practices was observed over time.

The indication of highgrading in the majority of the fleets and species studied highlights the need for technical conservation measures to be in tune with the discarding behaviour of fishers, and the factors that may influence such behaviour. Our results suggest that a reduction in MLS will not be effective in reducing discarding without an increased market acceptability of smaller fish. The recent management measures imposed in the Irish Sea and in the waters West of Scotland (changes in mesh size, imposition of effort regulation, and seasonal/area closures) were expected to increase the average length of fish in the catch, and consequently to reduce the proportion of fish discarded. However, the status of stocks in these areas is such that the mean length in the catch is actually decreasing. The increasing proportion of fish discarded in these areas is consistent with our finding that fishers discard larger fish when the average length in the catch is smaller. These results indicate that the management measures adopted have not been effective in protecting juvenile haddock and whiting. Clear understanding of the discard practices and market influences, allied to reliable monitoring of fishing activity, is needed to improve the efficiency of such management measures.

As discussed above, the models presented here may be used to evaluate the impact of changes or new management

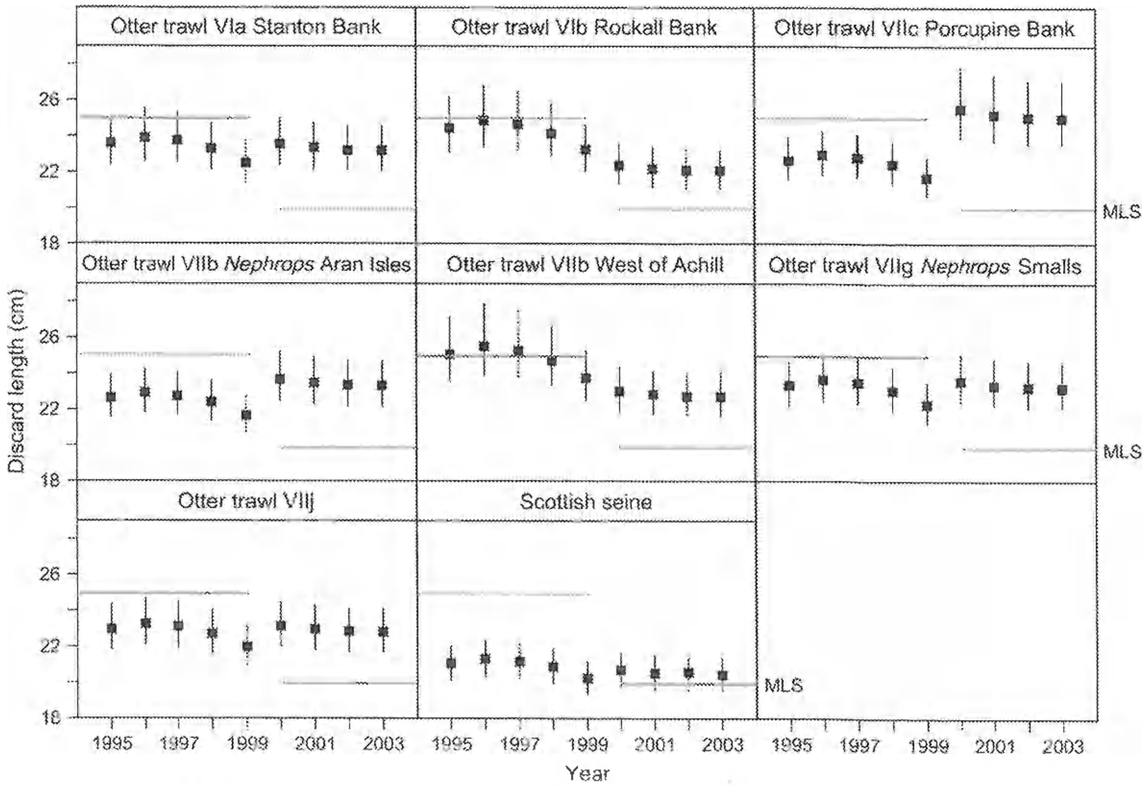


Figure 6. Predicted DL25, DL50, and DL75 (the length at which 25%, 50%, and 75% fish are discarded, respectively) based on the generalized additive model estimated of discard probability vs. length, fleet, MCL, year, MLS, and fleet × MLS interaction for megrim. Lines represent the DL25 and DL75; squares represent the DL50. Minimum landing size (MLS) is indicated by a horizontal line.

measures on discards. GAMs may be used to investigate the effectiveness of (and changes in) technical conservation measures (such as mesh size increases, changes in MLS) between gears and areas. GAMs can also detect the effect of landing restrictions on discards, for instance the impact of quota reductions and changes between quota systems (e.g. monthly to trip-based). The flexibility of GAMs also allows for the inclusion of other explanatory variables (such as area, gear, depth, species catch composition and abundance, or season) that are either not considered in the present study or are included in the fleet definition. Finally, GAMs can also be used to compare/calibrate other discard data estimation methods, for example based on selectivity data (Casey, 1996) or in population simulation studies (van Keeken *et al.*, 2003).

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