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**The effects of quota increases on discarding of common megrim *Lepidorhombus whiffiagonis* in the northern North Sea**

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**Abstract**

The common megrim *Lepidorhombus whiffiagonis* is a commercially important, high value flatfish species. It is occasionally targeted but, more often, is by-catch in the Scottish demersal trawl and seine fisheries in the northern North Sea. From the early 2000s discarding and high grading of megrim have been ubiquitous, primarily driven by what fishermen have perceived as restrictive quotas. Market-driven discarding is also common as the soft flesh of megrim, which bruises relatively easily in the trawl cod-end, reduces its commercial value. Since 2009 megrim quota in the northern North Sea has increased, primarily due to an increase in biomass reported from an annual fishery independent survey. In this study we compared megrim discard rates by Scottish trawl and seine vessels participating in the mixed demersal fishery in the northern North Sea prior to, and following recent quota increases. Results indicate that discarding has reduced from an average of 54% of the total catch in 2009 to 20% in 2012. High grading and selectivity patterns evident prior to the quota increases have also changed significantly.

Key words: Common megrim, *Lepidorhombus whiffiagonis*, discards, quota, high grading, North Sea

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# 1 Introduction

The United Nations Food and Agricultural Organisation (FAO) defines discards as the proportion of animal origin in the catch which is thrown away or dumped at sea for whatever reason (Kelleher, 2005). In EU waters the proportion of the catch discarded is typically between 10% and 60%, depending on the fishery (Anon, 2007). In the North Sea total annual discards are estimated at 500,000 to 800,000 tonnes per year (Kelleher, 2005). This equates to between 31% and 90% of the total catch, depending on the stock (Anon, 2007).

In 2007 the EU introduced a policy designed to reduce discards in European fisheries (Anon, 2007). This has resulted in the introduction of a number of discard bans. Currently, discard bans are found predominantly in single species fisheries as they do not have many of the inherent complications of demersal mixed species fisheries.

There are a number of scenarios that lead fishermen to discarding proportions of the catch. In the simplest terms, fishing vessels have a limited capacity for storing fish and, during a fishing trip, the species that will produce the highest return to the fishermen are selected and retained. Less valuable by-catch species, often referred to as trash species (Jennings et al., 2001), are returned to the sea. Also, many fish species in EC waters have a minimum landing size associated with them and fishermen are obliged to discard any fish that fall below that size (Anon, 1998). The situation becomes further complicated with the inclusion of quotas for target species. This can lead to high grading, the process whereby the most valuable proportion of the target species, often the larger individuals in the catch, are retained while smaller individuals, although possibly significantly above the minimum size, are discarded. Market influences also add to the discarding problem as fishermen will often discard a greater proportion of the catch, predominantly the smaller, less valuable portion, when market prices are low and conserve quota for periods of higher prices. This enables fishermen to obtain maximum returns for their time spent at sea. Gillis *et al*., (1995) devised a model of discarding within each fishing trip, taking each of the factors that affect discarding into account. Their model suggested that high grading should be more common towards the end of a fishing trip although it may be common at the beginning of a trip when the probability of a vessel's quota being filled is high. It also suggested that high grading increases with overall fish availability.

In the mixed demersal fishery of the North Sea, the total allowable catch (TAC) quota system is a significant contributor to discarding (Rijnsdorp et al., 2007). Target species often differ between vessels depending on available quota and, where species are abundant, quotas can be captured in a relatively short time. This has been the case with the common megrim *Lepidorhombus whiffiagonis*, a species that has been reported in greater numbers by fishermen executing the mixed demersal fishery in ICES Sub-Area IVa (northern North Sea). (Macdonald, P., unpublished data). This perception has been verified by a fishery independent survey which has also reported an increase in relative biomass in recent years (ICES, 2011a). However, in the mid-2000s the megrim TAC in IVa was reduced following an overall decrease in landings on the Northern Shelf. The increases in biomass in the late 2000s coupled with the decrease in quota led to discarding levels as high as 70% of the total catch (Laurenson and Macdonald, 2008). In 2008 the quota allocation for IV and IIa was 159 000 tonnes. In recent years there has been recognition of the increasing biomass in the northern North Sea and subsequent annual quota levels increased to 175 000 tonnes in 2010 and 184 500 tonnes in 2011 (ICES, 2011a). ICES further recommended that the TAC for 2012 should remain the same as for 2011.

Discarding of megrim is further complicated as individuals are prone to bruising, making them less desirable to buyers. This is primarily as a result of damage to the delicate muscle tissue by abrasion with other 'rough' species such as anglerfish and gurnards in the codend. Bruising is also more prevalent during periods of rough weather as the fishing gear tends to be less stable, causing abrasion between the codend and the fish. This can often result in higher discard rates, especially during periods when market prices are less favourable and TAC is restricted (Laurenson and Macdonald, 2008). The extent to which bruising occurs in megrim is not evident in any of the other species caught in the mixed fishery and there is currently no accounting for the composition of discards in relation to bruised fish. Indeed, ICES (2012) reported that there is a general paucity of megrim discard data in ICES Divisions IVa and VIa.

The aim of this study was to investigate recent changes in discard rates of megrim in the mixed demersal fishery in the northern North Sea (ICES Division IVa). Discard rates were compared over a five year period from 2008 to 2012 to determine the effect of quota increases on overall and individual vessel discarding patterns. Changes in the composition of discards were also investigated by determining how the proportion of small and bruised discards in the total catch varied over the study period. The relevance of a megrim TAC on the current mixed demersal fishery in the northern North Sea as well as the economic consequences of a complete discard ban in relation to bruised fish was also discussed.

## 2 Materials & methods

The International Council for the Exploration of the Seas (ICES) considers four stocks of megrim in European waters. In northern Europe three stock units are recognised (*L. whiffiagonis* and *Lepidorhombus boscii* are considered together): one in Divisions IVa and VIa (northern North Sea and west of Scotland respectively), one in Subarea VIb (Rockall) and one in Divisions VIIb-k and VIIIa,b,d,e (ICES, 2011a, b).

On board sampling was undertaken on vessels executing the mixed demersal fishery in the waters around the Shetland Isles (ICES Division IVa) (Figure 1). Data was collected from the two types of fishing vessel that predominantly catch megrim around Shetland: twin trawl and Scottish seine. To ensure that sampling was representative of the variation within the Shetland fishing fleet, vessels were randomly selected from a pre-defined list. Observer trips, each one lasting up to 7 days, were undertaken between May 2008 and June 2012. A total of 25 trips and 407 hauls (Figure 1) were sampled (Table 1). Vessels fished nets with 120mm mesh in the wings and 120mm mesh in the cod-end. Twin trawl tows normally lasted for six hours with up to four tows in any 24-hour period. Scottish seine tows lasted for two hours during daylight with 4-8 hauls/day depending on the time of year. The towing speed was approximately 3 knots for both types of vessel. All fishing was undertaken in depths between 88 and 200 m. During each haul the length and sex of individual fish were recorded from both the retained and discarded portions of the catch. Discards were categorised as 'small' (individuals below a length specified by the vessel prior to each haul) or 'bruised' (individuals deemed to be damaged beyond a profitable market level). The minimum landing size (MLS) for megrim in the northern North Sea is 20 cm. The extent of bruising varied between individual fish (Figure 2) and the resultant classification of fish as bruised varied across vessels and also across trips. To eliminate observer effect, all sampling was undertaken by a single observer.

Table 1 Number of vessels and hauls sampled for megrim from 2008-2012 in the northern North Sea.

| Year | Vessels sampled | Total Hauls |
|---|---|---|
| 2008 | 6 | 120 |
| 2009 | 2 | 34 |
| 2010 | 7 | 92 |
| 2011 | 6 | 112 |
| 2012 | 4 | 49 |

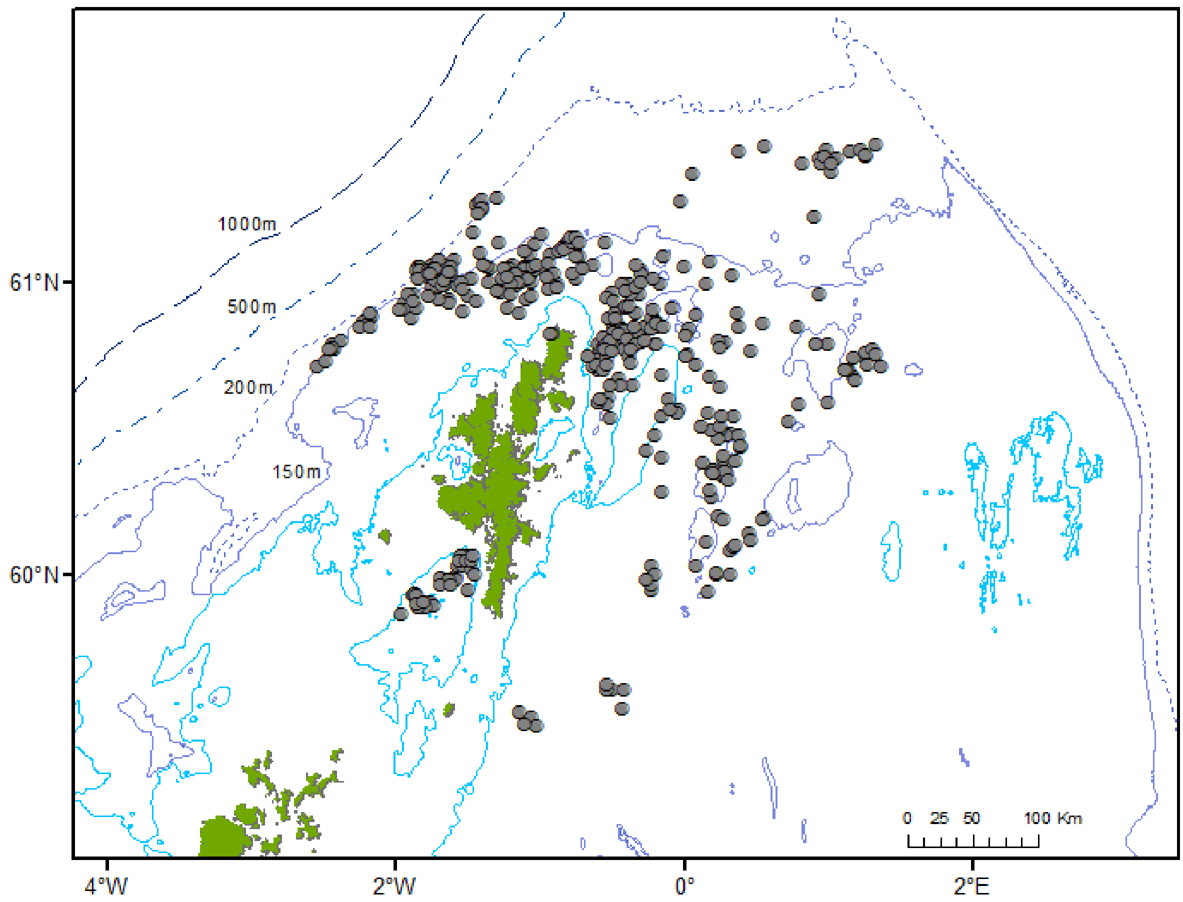


Figure 1 Map of study area with the location of individual fishing hauls from 2008-2012 highlighted (●).


Figure 2 Levels of bruising in *L. whiffiagonis* encountered during sampling. a) no bruising; b) slight bruising; c) moderate bruising; d) extensive bruising.

Data analysis

The proportion of bruised and small discards in the whole megrim catch was calculated for each haul. The average annual proportion of bruised and small discards was calculated collectively for all vessels and individually for four twin trawl vessels sampled over the study period. Although discard data from seiners contributed to the overall data set there were an insufficient number of trips undertaken over the study to compare annual variation of discards on individual vessels of this type.

All statistical analyses were conducted in the R environment, version 2.15.1 (R Development Core Team, 2008) using the packages *lme4* (Bates and Maechler, 2009) and *arm* (Gelman and Hill, 2006). A logistic regression model was fitted to the data to determine whether discarding had decreased between 2008 and 2012. Fish were scored as '1' if they had been discarded or '0' if they were retained. A similar approach was used to model the amount of small discards in the total catch from 2008 to 2012. In this model the response variable was '1' for small discards, or '0' for retained fish and bruised discards. Finally, a further logistic regression model was fitted to the data to determine whether any variation existed in the amount of bruised discards in the total catch from 2008 to 2012. In this model the response variables were scored as '1' for bruised discards, or '0' for retained fish and small discards.

The covariates in each of the models were 'Year', the year in which the fish was caught; 'Sex', the sex of the fish; and 'Length', the length of the fish in centimetres. Fish length was centred to the mean before being included in the model; this was done to make model coefficients easier to interpret (Gelman and Hill, 2006). Fishing data was collected from a number of fishing trips from a number of different fishing vessels on multiple occasions. Therefore, to account for the effects of pseudo-replication in the data, 'Trip' nested within 'Vessel' were included as random effects within the model. The use of these random effects accounts for the fact that data from the same fishing trip and data from the same vessel cannot be assumed to be independent.

Initially, a full model that included all the covariates as well as two-way interactions between 'Length' and 'Sex' and between 'Length' and 'Year' was fitted. Terms were then removed from the model, starting with higher order terms, until the model that gave the lowest AIC score (Akaike, 1974) was found. As logistic regressions are non-linear on the probability scale, logistic regression coefficients cannot be directly interpreted on the scale of the data. Therefore, to aid in the interpretation of logistic regression coefficients, average predictive comparisons were also calculated (Gelman and Hill, 2006). Diagnostic checks for each binomial model were conducted to ensure there were no patterns in the residuals (Gelman and Hill, 2006).

## 3 Results

The average proportion of megrim discarded from all hauls in each of the five years sampled is shown in Figure 3. The proportion of the total catch of megrim discarded peaked at an average of 0.54 (± 0.03 s.e.) per haul in 2009. In subsequent years this generally declined to an average of 0.20 (± 0.02 s.e.) in 2012.

The trend in overall discarding was also evident at the individual vessel level. The proportion of discards from four of the twin trawl vessels sampled regularly over the study period is shown in Figure 4. Although data is not available for each of the four vessels for the entire time series, there is a clear trend of decreased discarding in the latter years of the study.

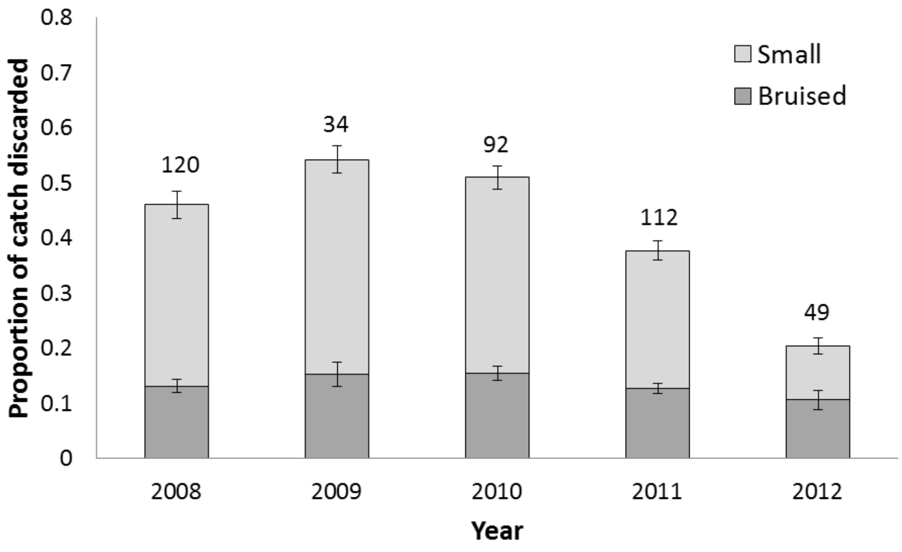


Figure 3 Average composition of *L. whiffiagonis* discards per haul for all vessels. ± s.e. bars and total number of hauls are also shown.

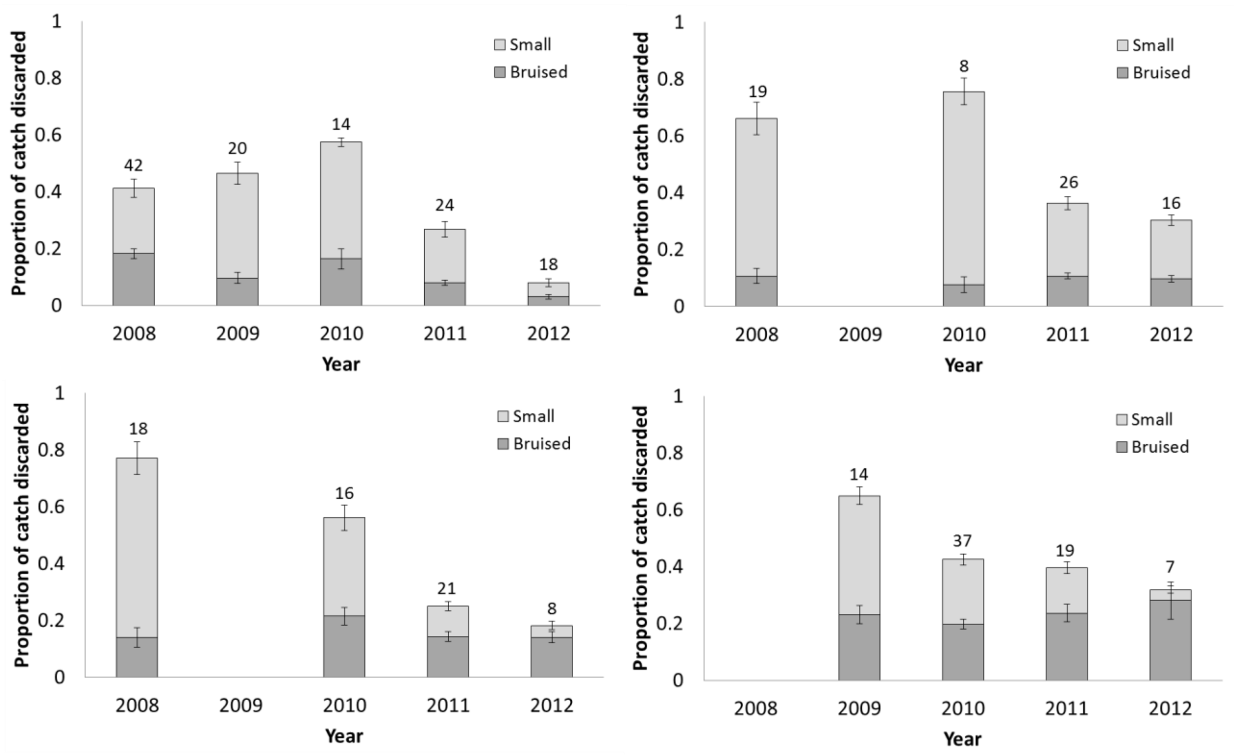


Figure 4 Average composition of *L.whiffiagonis* discards per haul for 4 individual twin trawl vessels. ± s.e. bars and total number of hauls are also shown.

Table 2 Discarded megrim below the minimum landing size (MLS) as a proportion of the total number of discards sampled from 2008-2012.

| Year | Total discards | Proportion below MLS |
|---|---|---|
| 2008 | 7187 | 0.0095 |
| 2009 | 1857 | 0.0005 |
| 2010 | 3661 | 0.0003 |
| 2011 | 3604 | 0.0044 |
| 2012 | 692 | 0.0014 |

Total discards

There was a significant decrease in total discards between 2008 and 2012 (Table 3) although discarding of fish <MLS was extremely low throughout the study period (Table 2). Model coefficients (calculated with fish length held constant at the population mean of 40 cm) indicate that the probability of discarding a fish of a given size decreased significantly, particularly in 2011 and 2012 (Table 4). Similarly, the average predictive differences suggest that an individual was 39% and 46% less likely to be discarded in 2011 and 2012 respectively than in 2008 (Table 4). The probability of being discarded decreased with increasing length and, using the 'divide by 4 rule', this equates to approximately 6-7% for every 1 cm increase in length (-0.27/4 = -0.0675). The significant interaction between length and the years 2010 and 2011 (Table 3) suggests that the relationship between the probability of being discarded and length differs during these years. Discarding between the sexes also varied with males having a significantly higher probability of being discarded than females (Table 3). The estimated variance of each of the random effects in the model suggests that there was greater variance in the probability of a fish being discarded between trips on the same vessel, than across the different vessels. There was no evidence of a significant interaction between sex and length and deleting this term from the model resulted in a reduction in AIC ($\Delta$AIC = -21).

Small discards

There was a significant decrease in small discards in the total catch between 2008 and 2012 (Table 3). Model coefficients indicate that there were significantly less small discards in 2011 and 2012. The average predictive differences also suggest that there was a greater chance of megrim being a small discard in 2008 than in later years in the study (Table 4). There was a significant interaction between year and length for all years except 2012 (Table 3), with smaller fish were less likely to be discarded after 2008. There was no significant difference in the probability of males and females being classed as a small discard. The estimated variance for each of the random effects in the model suggests that there was greater variance in the probability of a fish being discarded across trips on the same vessel, than across different vessels (Table 5). There was no evidence of a significant interaction between sex and length and deleting this term resulted in a reduction in AIC ($\Delta$AIC = -18).

Bruised discards

There was no significant difference in the proportion of bruised discards in the total catch between 2008 and 2012 (Table 3). Moreover, the estimated average predictive differences between 2008 and the following years were very small for both males and females, suggesting that bruised discarding differed little between years (Table 4). There was a significant interaction between year and length for all years, suggesting that the length at which fish were classed as bruised discards differed between years. There was also a significant interaction between sex and length indicating that the length of bruised discards differed between the sexes. Specifically, there was little variation between the length of bruised female discards and non-bruised females over the study period (Figure 5a). Conversely, male bruised discards were larger than non-bruised males in all years from 2008-2012 (Figure 5b). The estimated variance in each of the random effects was similar, suggesting there was little difference in the probability of bruised fish being discarded across trips on the same vessel and across different vessels (Table 5).

Table 3 Results for individual model covariates.

| **Total discards** | | | | **Small discards** | | | | **Bruised discards** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Coefficient | SE | *P*-value | Variable | Coefficient | SE | *P*-value | Variable | Coefficient | SE | *P*-value |
| Length | -0.27 | 0.005 | < 0.001 | Length | -0.79 | 0.02 | < 0.001 | Length | 0.07 | 0.004 | < 0.001 |
| Year - 2008 | 0.85 | 0.50 | 0.089 | Year - 2008 | 0.92 | 1.09 | 0.40 | Year - 2008 | -2.09 | 0.23 | < 0.001 |
| Year - 2009 | 0.14 | 0.50 | 0.77 | Year - 2009 | -1.59 | 1.10 | 0.15 | Year - 2009 | -1.78 | 0.22 | < 0.001 |
| Year - 2010 | 0.40 | 0.49 | 0.43 | Year - 2010 | -0.53 | 1.10 | 0.63 | Year - 2010 | -1.97 | 0.23 | < 0.001 |
| Year - 2011 | -1.95 | 0.50 | < 0.001 | Year - 2011 | -6.44 | 1.11 | < 0.001 | Year - 2011 | -2.15 | 0.23 | < 0.001 |
| Year - 2012 | -2.55 | 0.51 | <0.001 | Year - 2012 | -8.44 | 1.14 | <0.001 | Year - 2012 | -2.34 | 0.24 | <0.001 |
| Sex (M) | 0.35 | 0.06 | <0.001 | Sex (M) | 0.04 | 0.07 | 0.54 | Sex (M) | -0.01 | 0.08 | 0.89 |
| Length×2009 | -0.001 | 0.01 | 0.42 | Length×2009 | 0.35 | 0.02 | <0.001 | Length×2009 | -0.02 | 0.009 | 0.045 |
| Length×2010 | -0.03 | 0.01 | 0.001 | Length×2010 | -0.07 | 0.03 | 0.011 | Length×2010 | 0.02 | 0.008 | 0.041 |
| Length×2011 | -0.04 | 0.01 | <0.001 | Length×2011 | 0.12 | 0.02 | <0.001 | Length×2011 | -0.05 | 0.007 | <0.001 |
| Length×2012 | -0.01 | 0.01 | 0.26 | Length×2012 | -0.09 | 0.05 | 0.06 | Length×2012 | -0.14 | 0.012 | < 0.001 |
| | | | | | | | | Length × Sex | 0.14 | 0.014 | <0.001 |

Length was centred to the population mean of 40 cm. *P*-values for each year denote whether the intercept in that year was different from 0.5, rather than providing a comparison between years. Standard error (SE) is also shown.

Table 4 Probabilities and average predictive difference for each category of discards from 2008-2012.

| | **Total discards** | | **Small discards** | | **Bruised discards** | | |
|---|---|---|---|---|---|---|---|
| Year | Probability of being discarded (± 95% CI) | Average predictive difference vs. 2008 Female | Probability of being discarded (± 95% CI) | Average predictive difference vs. 2008 Female | Probability of being discarded (± 95% CI) | Average predictive difference vs. 2008 Female | Average predictive difference vs. 2008 Male |
| 2008 | 0.70 (0.46 – 0.86) | NA | 0.72 (0.22 – 0.95) | NA | 0.11 (0.07 – 0.16) | NA | NA |
| 2009 | 0.53 (0.30 – 0.75) | -0.11 | 0.17 (0.03 – 0.64) | -0.23 | 0.14 (0.10 – 0.21) | 0.03 | 0.03 |
| 2010 | 0.59 (0.36 – 0.79) | -0.08 | 0.37 (0.06 – 0.84) | -0.10 | 0.12 (0.08 – 0.18) | 0.02 | 0.02 |
| 2011 | 0.12 (0.05 – 0.27) | -0.39 | 0.002 (0.0 – 0.01) | -0.44 | 0.10 (0.07 – 0.15) | -0.01 | -0.03 |
| 2012 | 0.07 (0.03 – 0.17) | -0.46 | 0.0002 (0.0 – 0.002) | -0.44 | 0.09 (0.06 – 0.13) | -0.02 | -0.08 |

The probability of being discarded was calculated with sex and length held constant. The average predictive difference is calculated for females in Total and Small discards (the same result would apply to males due to the significant effect of sex) and for females and males in Bruised discards (due to the existence of a significant interaction between sex and length).

Table 5 Variance associated with random effects for individual models.

| | Intercept variance | | |
|---|---|---|---|
| Random term | **Total discards** | **Small discards** | **Bruised discards** |
| Trip | 0.72 | 1.69 | 0.18 |
| Trip nested in Vessel | 2.55 | 17.44 | 0.33 |

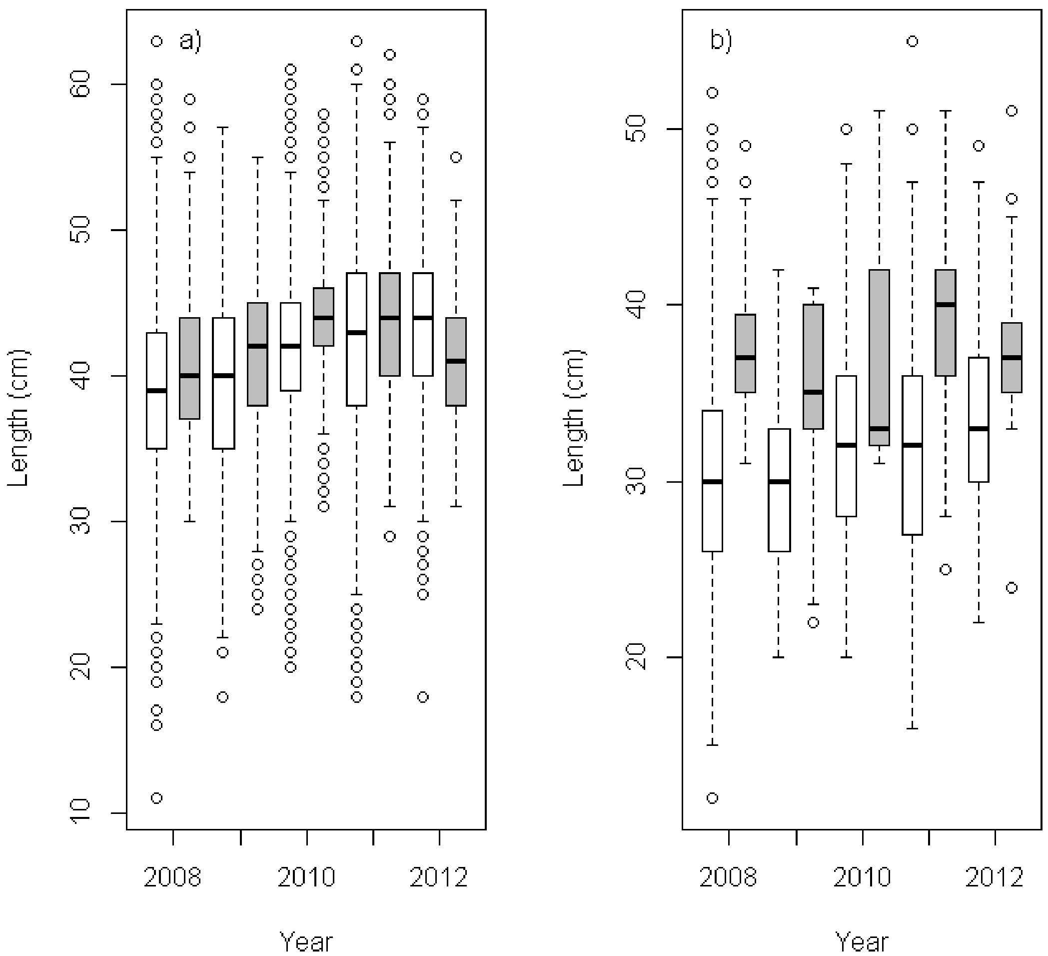


Figure 5 Box plots of length frequency of (a) female and (b) male megrim. White boxes represent non-bruised fish, including both retained fish and small discards, grey boxes represent bruised discards.

## 4 Discussion

The results of this study demonstrate that discarding of megrim in the northern North Sea has decreased significantly in recent years. There have also been significant changes in discarding patterns, notably a decrease in the average minimum size discarded. The added complexity inherent in megrim discarding due to the presence and magnitude of bruised individuals in the catch is also evident from this study.

Fernandes et al. (2011) noted that discarding generally falls into three categories: undersized (fish below the MLS), regulatory (discarding due to quota or other management restrictions) and discretionary (catch selection behaviour such as high grading, intended to maximise profits). The extent to which the three categories affect discard rates varies between fisheries and species. Further, Feekings et al. (2012) reported that the interaction of a multitude of highly species specific factors were influential in affecting fishermen's decision to discard.

The decrease in discarding of small megrim evident here corresponds with recent increases in TAC and suggests that the extent to which discarding of small megrim >MLS is undertaken is largely regulatory i.e. driven by the available TAC. However, despite the decrease in the minimum retained size in recent years, there is still a significant proportion of the catch >MLS discarded. Indeed, catches of undersized megrim were almost negligible throughout the study, indicating that the majority of fish < MLS are not being retained in the gear. Given the fact that discarding is still at an average of 20% of the total catch in 2012, this suggests that high grading is still an issue despite the recent increases in TAC.

Conversely, levels of bruised megrim discarding did not change significantly, implying that factors other than available TAC may influence the decision to discard these individuals. It may be expected that an increase in TAC would provide more opportunity to land fish that would otherwise be deemed to be of lesser commercial value, such as bruised individuals. However, retention of bruised fish can become problematic irrespective of TAC restraints as the relative returns can be uneconomical. Market prices achieved for bruised megrim can often be less than 50% of the price of the smallest grade of undamaged fish, irrespective of the size of the bruised fish (A. Crossan, pers. comm.). This suggests that landing smaller individuals will be of more economic value than landing bruised fish, corresponding with the results of this study. This also creates a potential dilemma, given the current drive to ban discarding, of low value, inferior fish being landed and using up what may be perceived as a limited TAC. In the past, discarding of bruised megrim has been as high as 30% of the total catch from a trip (Laurenson and Macdonald, 2008) and, as such, a discard ban may have the potential to significantly reduce the value of the species to fishers.

A number of studies have highlighted the significance of market prices as a driver in discarding (Clucas, 1996; Depestele et al., 2011). Given the fact that megrim prices typically increase threefold between the smallest and largest grades, market prices may also influence the minimum size at which megrim will be retained. This was especially evident early in the study where TAC was limited and high grading was widespread. It is also important to note that market prices for megrim can fluctuate on a seasonal basis with prices for the largest grades during stagnant price periods decreasing to similar prices received for the smallest grades during periods of increased prices.

A further significant finding from the study was the difference in the length distribution of bruised and non-bruised males. The results indicate that the majority of male fish that were discarded as bruised were similar in length to that of female bruised discards. The difference in length frequencies of non-bruised males for all years may have been due to sexual dimorphism, as female megrim are known to grow faster and larger than males (Macdonald et al., 2012). Given the effect of dimorphism, the proportion of males in the catch would be expected to be higher at smaller lengths and may account for the lower average size of non-bruised fish. This is also reflected in the significant difference between the sexes in discarding of small fish as a larger proportion of males would be present in smaller size classes. Further, differences in overall discarding between the sexes were primarily driven by changes in discarding of smaller individuals, where the proportion of each sex is highly skewed towards males. This is in keeping with other flatfish species where the landed part of the catch is typically more biased towards females while the discarded portion of the catch may contain disproportionately more males (Kell and Bromley, 2004). This has the potential to cause distortion in the stock assessment process, especially as many assessments utilize catch data and do not consider discards.

Megrim in the northern North Sea is predominantly caught as a by-catch for vessels targeting the anglerfish fishery. As with many other by-catch species, fishing effort is primarily driven by available TAC for the target species. Therefore, given a scenario of limited TAC for a by-catch species and adequate TAC for a targeted species, discarding of the by-catch species will persist as fishing for the target species continues. This scenario serves to question the validity and efficacy of a TAC for a predominantly by-catch species such as megrim in the northern North Sea.

## Conclusion

Levels of megrim discarding in the northern North Sea have decreased significantly in recent years, primarily as a result of a decrease in the minimum retained size. However, high grading of smaller fish greater than the minimum landing size continues, albeit to a lesser extent. Bruised fish continue to be discarded at similar levels to previous years due to their limited economic value. The results of this study indicate that discarding of megrim may continue in future years under the current TAC. Further to this, an outright ban on discarding will reduce the value of the species to fishers due to the necessity to land low value bruised fish. While this study focuses on annual variation in discarding rates, further work is required to investigate the extent to which the seasonal effects of market prices and weather influence discarding patterns.

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