The contribution of quota to the discards problem: a case study on the complexity of common megrim Lepidorhombus whiffiagonis discarding in the northern North Sea

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Published in:
ICES Journal of Marine Science

Publication date:
2014

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Abstract

The common megrim *Lepidorhombus whiffiagonis* is a commercially important, high value flatfish species. From the early 2000s discarding of common megrim in the northern North Sea has been widespread. In this study we investigated temporal variation in megrim discarding in the mixed demersal fishery in the northern North Sea prior to, and following recent quota increases. Furthermore, logistic regression models were applied to investigate the effects of a range of explanatory factors on the probability of individual fish being discarded. Results indicate that discarding on the vessels sampled has declined from an average of 54% of the total common megrim catch in 2009 to 20% in 2012. Model outputs also suggest that the likelihood of a fish being discarded decreases significantly ($P<0.001$) with increasing quota. The current megrim TAC serves only to regulate landings and does little to regulate fishing mortality. Additionally, the proposed reform of the CFP, including the move towards a discards ban and the implementation of maximum sustainable yield, raises a number of concerns that

need to be addressed if the northern North Sea mixed demersal fishery is to be managed sustainably and remain economically viable in the future.

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

1 Introduction

The United Nations Food and Agricultural Organisation (FAO) defines discards as the proportion of the total organic material 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 within demersal fisheries is typically between 20% and 60% by weight, and is largely fishery- and area-dependent (Anon, 2007). In the North Sea total annual discards during the period 1992-2001 were estimated at 500,000 to 800,000 tonnes per year (Kelleher, 2005).

In 2007 the EU introduced a policy designed to reduce discards in European fisheries (Anon, 2007). This has resulted in the introduction of management measures such as the prohibition of high grading in the North Sea (Anon, 2009). Under this regulation, there is a requirement for any quota species caught in the North Sea to be landed if they are above the minimum landing size. Furthermore, voluntary schemes such as the North Sea catch quota management system (Anon, 2011a) enable the operation of a fully documented fishery with the use of remote electronic monitoring. The scheme was intended to reduce cod discards by ensuring that all cod catches above the minimum landing size were landed. However, the scheme is not currently in operation across the entire demersal fleet (Anon, 2011a). At present, outright discard bans are found predominantly in single-species fisheries as they do not have many of the inherent complications of demersal mixed-species fisheries (Anon, 2007). The European Commission has legislated for a phased introduction of a ban on discarding beginning with pelagic species in 2015 and demersal species in 2016 (Anon, 2013).

One of the contributing factors to discarding is high grading, the process by which individual fish are preferentially retained over others to maximise economic returns. Less valuable by-catch species, as well as species with no economic value (often referred to as 'trash species' (Jennings *et al.*, 2001)), are returned to the sea. The situation becomes further complicated by having quotas for individual species because catch compositions can be difficult to predict. This can exacerbate high-grading as the most valuable proportion of the target species, often the larger individuals in the catch, are retained while smaller and/or damaged individuals, although above the minimum size, are discarded. Market influences also affect discarding as fishermen will often discard a greater proportion of the catch when market prices are low and conserve quota for periods of higher prices, where possible (Feekings *et al.*, 2013). This enables fishermen to obtain maximum returns for their quota. To try to quantify the importance of the various factors that contribute to fishermen's decision-making process in relation to discarding, Gillis *et al*., (1995) devised a model of discarding within each fishing trip, taking each of the factors that affect discarding into account. Furthermore, Feekings *et al*. (2012) reported that the interaction of a multitude of highly species-specific factors were influential in affecting fishermen's decisions to discard. They investigated the effects of 11 variables affecting discards within a demersal trawl fishery and recommended that an understanding of the factors that influence discarding is essential for the future management of fish stocks.

In the mixed demersal fishery of the North Sea, the total allowable catch (TAC) quota system, which is in fact a Total Allowable Landings (TAL) system, is a significant contributor to discarding (Rijnsdorp *et al.*, 2007). The composition and quantity of target species often differ between vessels depending on available quota and, when fishermen target grounds where certain species are abundant, quotas can be exhausted in a relatively short time. This has been especially evident for the common megrim *Lepidorhombus whiffiagonis*, a species that has been the subject of discarding and high grading in recent years (Laurenson and Macdonald, 2008). Individuals deemed to be too small, although often considerably larger than the minimum landing size, are often discarded. The criteria for discarding a megrim as being too small are highly subjective and may vary across vessels, depending on a number of factors such as market prices and available quota (Laurenson and Macdonald, 2008).

Another important factor contributing to the high grading of megrim is its susceptibility to bruising, with damaged individuals less desirable to buyers. This is primarily a result of damage to the delicate muscle tissue by abrasion with other ‘rough’ species such as anglerfish (*Lophius* spp.) and grey gurnards (*Eutrigla gurnardus*) in the codend. Bruising may be 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 contribute to higher discard levels, especially during periods when market prices are less favourable and quotas are 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 what proportion of megrim discards are bruised fish. Indeed, ICES (2012a) reported that there is a general paucity of megrim discard data in ICES Divisions IVa and VIa.

Given the anecdotal data alluding to the extensive and complex discarding patterns of this species in the northern North Sea, the aims of this study were:

1. To investigate temporal variation in discarding of megrim in the Scottish mixed demersal fishery in the northern North Sea (ICES Division IVa) from data collected during observer trips on commercial fishing vessels at the Shetland Isles. Discard rates (no./hr) were calculated for these vessels and compared over a five year period from 2008 to 2012. Changes in the composition of megrim discards were investigated by determining how the proportion of small and bruised discards within the total catch varied over the study period.

2. To apply a logistic regression model to the data collected during observer trips to investigate the effects of the explanatory variables quota, fish length, fish sex (to determine the effect of sexual dimorphism on the probability male and female megrim being discarded) and wind strength on the probability of a fish being classed as a

discard from 2008 to 2012. Furthermore, in order to account for the two sub-components of the discarded portion of the catch, additional models were applied to investigate the effects of explanatory variables on the probability of a fish being classed as a small or bruised discard.

The relevance of a megrim TAC in the current mixed demersal fishery in the northern North Sea as well as the consequences of a complete discard ban within the reformed Common Fisheries Policy (CFP) are also discussed.

2 Recent changes in megrim TAC

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 ICES Divisions IVa and VIa (northern North Sea and west of Scotland), one in Division VIb (Rockall) and one in Divisions VIIb-k (Celtic Sea) and VIIIa,b,d (Bay of Biscay) (ICES, 2011c, b). In southern Europe Divisions VIIIc and IXa (Southern Bay of Biscay and Portugal) constitute a further stock where *L. whiffiagonis* are considered separately to *L. boscii*. This study was undertaken in Division IVa.

In the 2004 the megrim TAC in IIa and IVa (the TAC is set jointly for IIa and IVa although catches are almost exclusively from IVa) was reduced from 3000 tonnes to 1890 tonnes following ICES advice to decrease the TAC in line with landings on the Northern Shelf (Rockall, West of Scotland and northern North Sea). The TAC was reduced further in 2005 to 1740 tonnes and again in 2007 to 1480 tonnes. Anecdotal evidence from fishermen working in the mixed demersal fishery in IVa suggests that megrim increased in numbers from approximately 2006 onwards (Laurenson and Macdonald, 2008). This perception has been verified by an annual fishery-independent survey, undertaken by Marine Scotland, which has also reported an increase in relative biomass in recent years (ICES, 2011c). The increase in megrim biomass correlated with increased catches and, coupled with the reduced TAC, resulted in estimated discarding levels as high as 70% of the total megrim catch in the Shetland demersal fishery (Laurenson and Macdonald, 2008). This is considerably higher than estimates of megrim discards from neighbouring stocks such as ICES Divisions VIIb-k and VIIIa,b,d where discarding in recent years was estimated at an average of 25% of the total catch (ICES, 2011a). There has recently been recognition of the increasing biomass in the northern North Sea and subsequent annual TAC levels increased to 1750 tonnes in 2010, 1845 tonnes in 2011 and 2012, and 1937 tonnes in 2013 (ICES, 2013a).

The Shetland Fish Producers' Organisation (SFPO) is currently allocated approximately 14% of the total UK annual megrim TAC for IVa. This quota is then distributed between the vessels within the PO on a monthly basis. Quota allocation and uptake for vessels in the PO are shown in

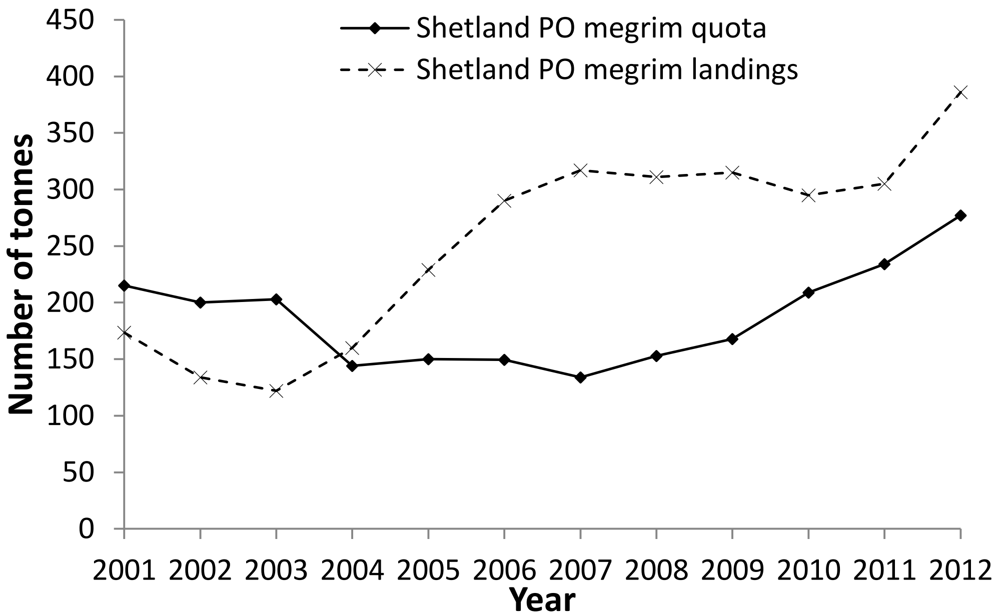

Figure 1. Prior to 2004 the annual PO quota allocation was 8% of the total UK annual megrim TAC and was consistently higher than landings. In subsequent years landings from this PO increased considerably while the PO quota allocation dropped, as a result of decreases in UK megrim TAC, from 150 tonnes in 2005 to 134 tonnes in 2007. The localised catch-quota

mismatch was addressed through the renting of additional quota from other Producer Organisations. During the period of the current study (2008-2012) PO quota allocation, as well as the percentage allocation of the total UK annual megrim TAC, has risen year on year from 153 tonnes (approximately 10% of UK allocation) in 2008 to 277 tonnes (approximately 14% of UK allocation) in 2012, decreasing the mismatch between PO quota allocation and landings.

3 Materials & methods

3.1 Observer sampling

On board sampling was undertaken on eight vessels (6 twin trawl and 2 Scottish seine) from the demersal fleet based in the Shetland Islands, Scotland and working in the mixed demersal fishery in ICES Division IVa (Figure 2). Twin trawl and Scottish seine are the two types of fishing gear predominantly used to catch megrim in this area. To ensure that sampling was representative of the variation within the fleet, vessels were randomly selected using a random number generator function in Microsoft Excel from a pre-defined list of the 10 PO vessels (6 twin trawl and 4 seine) that predominantly catch megrim. The main target species for each of the twin trawl vessels over the study period was consistently anglerfish and the main target species for seine net vessels were haddock and whiting. Observer trips, each one lasting between 2 and 8 days, were undertaken between May 2008 and March 2012. To eliminate observer effect, all sampling was undertaken by a single observer. A total of 25 trips (22 twin trawl and 3 seine) and 407 hauls (Figure 2) were sampled (Table 1). The fishing gear used by each of the vessels was consistent over the study period. Vessels fished with nets with 120mm mesh in the wings and 120mm mesh in the codend. 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 megrim were recorded from both the retained and discarded portions of the megrim within the catch. Discards were categorised as ‘small’ or ‘bruised’. Small discards comprised individuals below a length specified by the crew prior to each haul and varied across vessels and trips. The length specified by the crew was always above the minimum landing size of 20 cm. The sex of the fish was not considered in the catch selection process. Bruised discards consisted of individuals deemed to be damaged beyond a profitable market level. The extent of bruising varied between individual fish and the resultant classification of fish as bruised also varied across vessels and trips. All catch sorting was undertaken by the crew.

3.2 Data analysis

3.2.1 Temporal variation in discarding

The proportions by number of bruised and small discards in the whole megrim catch were calculated separately for each haul. The average annual proportions of bruised and small discards were calculated collectively for all vessels and separately by vessel for four twin trawl vessels. Only four twin trawl vessels were sampled frequently enough to compare annual variation in discards on individual vessels. 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.

In order to determine whether other contributory factors, such as changes in population structure or changes in catch structure, were influencing discarding, a Spearman rank-order correlation test was used to determine whether there was a correlation between the overall proportion of small megrim discards in the catch and the overall proportion of small megrim (<35 cm) in the catch for each of the 25 trips. Furthermore, the annual proportion of small megrim discards in the catch were compared with fishery-independent survey data using a Spearman rank-order correlation test to determine whether the proportion of small megrim discards correlated with the proportion of small megrim (<35 cm) within the population. Fishery-independent survey data was downloaded from the ICES DATRAS (DAtabase of TRAwl Surveys: http://datras.ices.dk) database for the years 2008-2012. Data was selected from the North Sea International Bottom Trawl Survey (NSIBTS) Quarter 1 and Quarter 3 surveys and combined. Megrim distribution in the North Sea is predominantly confined to the deeper water around Shetland and along the continental shelf edge. NSIBTS data is therefore representative of localised patterns in population structure.

3.2.2 Logistic regression models

All statistical analyses were conducted in the R environment, version 2.15.1 (R Development Core Team, 2008). A logistic regression model was fitted to the data using the packages *lme4* (Bates and Maechler, 2009) and *arm* (Gelman and Hill, 2007) to investigate the probability that a fish would be classed as a discard between 2008 and 2012. A total of 37,403 fish were included in the analyses. Fish were scored as '1' if they had been discarded or '0' if they were retained. A similar approach was used to model the probability that a fish would be classed as a small discard 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 estimate the probability that a fish would be classed as a bruised discard between 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 considered in each of the models were 'Quota', the vessel specific quota (kg) for each vessel for a particular month; 'Sex', the sex of the fish; 'Wind Strength', the strength of the wind when a particular haul took place, measured in accordance with the Beaufort wind force scale from 1 (light wind) up to 9 (severe gale), and 'Length', the length of the fish in centimetres. 'Sex' was included in the model to determine whether sexual dimorphism had an effect on the probability of male and female megrim being discarded. Given the anecdotal evidence of damage to megrim in the trawl being exacerbated during bad weather, the covariate 'Wind Strength' was included in order to examine the effect of wind strength on the probability of a fish being classed as a discard. Fish length was centred to the population mean of 40 cm before being included in the model to make model coefficients easier to interpret (Gelman and Hill, 2007). Similarly, Quota (mean-centred and divided by the standard deviation) was z-transformed prior to inclusion in the model because the inclusion of raw quota data caused problems with model convergence (convergence problems occurred because the quota data contained large numbers, often with intervals between different values).

Data was collected from a number of fishing trips on 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’ was included as a random effect within the model. ‘Stat Square’ (the pre-defined ICES statistical area where the individual fish was caught) was included as an additional random effect in order to account for spatial variation in discarding across statistical areas. Month was also included as a random effect to account for temporal variation in sampling across years. Randomizations conducted in the *fishmethods* package suggested that there were differences in the overall catch length frequency distribution between years. In order to account for this, ‘Year’ was also included as a random effect in the models to account for any differences in the length-frequency distribution of catch data between years. Random intercepts allow the intercept or magnitude of the response to vary between groups, allowing variance to be separated into a within and between-group (e.g. between vessels) variance component. This accounts for the fact that measurements from the same group are inter-correlated and helps to avoid pseudo-replication (Millar and Anderson, 2004; Gelman and Hill, 2007).

Initially, a full model that included all the covariates as well as all two-way interactions between the variables 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. Diagnostic checks for each binomial model were conducted to ensure there were no patterns in the residuals (Gelman and Hill, 2007).

4 Results

Temporal variation in discarding

The individual hauls were distributed around the Shetland Isles over the five years of the study (Figure 2) with no considerable changes or patterns in fishing locations evident across years. Observer trips were distributed randomly throughout the month for each year and there was no significant pattern (Figure 3) or correlation (r=0.12, n=25, P>0.05) evident over the study period. The average proportion of megrim discarded from all hauls in each of the five years sampled is shown in Figure 4. 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 decrease in overall discards was primarily as a result of a decrease in the proportion of small discards from 0.39 (± 0.02 s.e.) in 2009 to 0.10 (± 0.01 s.e.) in 2012. The proportion of bruised discards remained relatively constant over the study period, with a small decline from an average of 0.15 (± 0.02 s.e.) in 2009 and 2010 to 0.10 (± 0.01 s.e.) in 2012. Discarding of fish below the minimum landing size was extremely low throughout the study period (Table 1).

The proportion of discards from the four twin trawl vessels sampled regularly over the study period is shown in Figure 5. Although data are not available for each of the four vessels for the entire time series, there is a similar trend of decreased discarding for each of the vessels sampled in the latter years of the study.

There was no significant correlation between the annual proportion of small megrim discards and the proportion of small megrim (≤ 35 cm) in the NSIBTS survey data over the study period (r=0.02, n=5, P>0.05). However, it should be noted that power analysis undertaken on the comparison of small discards and NSIBTS data, due to the use of only five samples, was low. There was also no significant correlation between the annual proportion of small megrim discards and the proportion of small megrim (≤ 35 cm) in the overall catch (r=0.16, n=25, P>0.05) for the vessels sampled. This suggests that changes in the proportion of small megrim discards within the total megrim catch were due to factors other than changes in population structure and catch structure.

Logistic regression models

Total discards

There was a significant two-way interaction between Quota and Wind Strength (P<0.001). Interpretation of the two-way interaction between Quota and Wind Strength based on the model coefficients (Table 2) suggests that, as Quota increases, the probability of being discarded declines; this decline becomes steeper as wind strength increases. Furthermore, the probability of being discarded decreases with increasing length (Table 2). This suggests that the larger a fish is, the less likely it is to be discarded. As Quota increases, the influence of Length on the probability of being discarded decreases slightly (Figure 6). Despite the two-way interaction between Quota and Length not being significant (P=0.09), inclusion of the interaction in the model increased the AIC score. Moreover, the likelihood of being discarded decreases further as quota available for a given month increases. The significant interaction between Sex and Length (P<0.001) suggests that, as length increases, the probability of being discarded decreases more steeply in males than it does in females. The estimated variance of each of the random effects in the model suggests that there was considerable variance in the probability of a fish being discarded between months. There was little variation between locations (Stat Square), vessels, years and between trips on the same vessels (Table 3).

Small discards

There were significant two-way interactions between Quota and Wind (P<0.001) and between Length and Sex (P<0.01). As Quota increased, the probability of being classed as a small discard generally decreased; this decline became steeper as Wind Strength increased (Figure 7). With Length held constant at the population mean, male megrim had a significantly lower probability of being classed as a small discard (P<0.05) (Table 2). As length increased, the probability of being classed as a small discard decreased. However, the two-way interaction between Sex and Length (P<0.01) suggests that the decline in the probability of being classed as a small discard with increasing length is steeper in males than females, although only marginally. There was no evidence of a significant interaction between Quota and Length as there was in the total discards model and deleting this term resulted in a reduction in AIC (ΔAIC = -1). The estimated variance of each of the random effects in the model suggests that there was considerable variance in the probability of a fish being discarded between vessels, between trips on the same vessels, and between years and months. There was little variation between locations (Stat Square) (Table 3).

Bruised discards

There were significant two-way interactions between Length and Sex ($P<0.001$) and Length and Quota ($P<0.001$). Model coefficients suggest that as Quota increased, the probability of a fish being classed as a bruised discard decreased; the negative interaction between Quota and Length suggests that the importance of Quota increases as fish length is increased (Figure 8). When Length was held constant at the mean (40 cm) there was no evidence that Sex influenced the probability of a fish being classed as a bruised discard. In both males and females the probability of being classed as a bruised discard increased with increasing length. However, the interaction between Sex and Length suggests that the importance of Length as a predictor increased more steeply in males than in females. There were considerably more bruised female than male discards at each cm length increment. Wind strength had no impact upon whether a fish was classed as a bruised discard, nor was there strong evidence of an interaction between Quota and Wind Strength as there was with the small discards and total discards models (removing the term: ΔAIC = -5). The estimated variance in each of the random effects was broadly similar, with the least variation evident between years and months (Table 3).

5 Discussion

The results of this study suggest that, from 2008 to 2012, increases in TAC and subsequent vessel specific quotas may have resulted in a significant decrease in discarding of megrim for the vessels sampled here. The added complexity in megrim discarding due to the presence and magnitude of bruised individuals in the catch is also evident. Furthermore, high grading of megrim has been prevalent over the study period, despite the introduction of the high grading ban in 2009 (Anon, 2009). This suggests that, for the vessels sampled here, the ban has been disregarded to a great extent.

Fernandes *et al*. (2011) noted that discarding generally falls into two categories: regulatory (fish below the minimum landing size and discarding due to quota or other management restrictions) and discretionary (i.e. unregulated species with no minimum landing size or quota where catch selection behaviour such as high-grading is intended to maximise profits). The extent to which the two categories affect discarding varies between fisheries, species and areas. In the case of North Sea megrim, discarding appears to be primarily driven by regulatory restrictions.

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 greater than the minimum landing size is undertaken is largely regulatory i.e. driven by the available TAC. Catchpole *et al*. (2005) noted that, while quotas are a driver of discards in the North Sea, other factors, in combination, contribute more to the total quantity of discards. It has also been suggested that there is evidence that many fishermen land all the marketable fish they catch and that discards are mostly juvenile fish, although this is probably species-dependent (Catchpole *et al*., 2005). The results of this study indicate that, in the case of North Sea megrim, discards are predominantly above the minimum landing size. Indeed, catches of undersized megrim were almost negligible throughout the study, indicating that the majority of fish below minimum landing size are not being retained in the gear. Further, given the fact that discarding of megrim is still at an average of 20% by number of the total megrim catch in 2012, high-grading is still an issue despite the recent increases in TAC. This suggests that the current levels of TAC are still restrictive and/or there is limited market demand for smaller or bruised individuals. Furthermore, improvements in the selectivity of the gear could be investigated to assist in reducing the quantity of small discards.

As quota is distributed on a monthly basis, there is the potential for sorting practises to alter during the month as quota becomes more or less restrictive. During the current study it was not possible to take into consideration any potential variation in sorting practises across a given month as the observer coverage during this study was not sufficient to determine whether this was the case. However, observer trips were undertaken at different times during the month, ensuring that observer coverage reduced the effect of any potential differences in sorting practises.

The significant effect of length on the probability of a megrim being classed as a bruised discard may have been affected by fishers' decisions when categorising megrim discards. If fishers were categorising all small megrim (including bruised individuals) as small discards, only the larger bruised megrim would be classed as bruised discards, possibly contributing to the significant effect of length seen here. The probability of a fish being classed as a bruised discard decreased significantly with increasing quota, albeit to a lesser extent than small discards. This implies that factors other than available quota may influence the decision to discard these individuals. It may be expected that an increase in quota 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 quota constraints 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 (Shetland Seafood Auction, pers. comm.). This suggests that within quota constraints 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 quota.

A number of studies have highlighted the significance of market prices as a driver in discarding (Clucas, 1996; Depestele *et al.*, 2011). As megrim prices typically increase threefold between the smallest and largest grades (Shetland Seafood Auctions, pers. comm.), market prices may also influence the minimum size at which megrim will be retained. This may have been what was driving high-grading in the beginning of the study when quota was limited. It is also important to note that market prices for megrim can fluctuate significantly, with prices for the largest grades during stagnant price periods decreasing to similar prices received for the smallest grades during periods of increased prices. Unfortunately, the frequency of sampling undertaken for this study was not sufficient to carry out an extensive intra-annual study of discarding patterns and additional work is required in order to investigate this further.

A further notable finding of the study was the interaction of wind strength and quota on the discarding of small megrim. An increase in the probability of small megrim being discarded with increasing wind strength suggests that sorting practises are influenced by weather. This may be a result of the crew selecting and processing less of the lower value small individuals during less favourable conditions. Model outputs suggest that this is further exacerbated as quota becomes more restricted. Conversely, similar patterns of increased bruised discards in the catch during higher wind strengths were not evident, despite the anecdotal evidence to the contrary. This may suggest that factors other than wind strength have an effect on bruising. As such, further work is required to investigate the possible interaction between the proportion of bruised discards in the catch and other variables such as catch volume and composition.

Given the considerable proportion of bruised megrim discarded from the total catch (10-15%), it may be beneficial for fishermen to investigate potential methodologies for reducing flesh damage during fishing operations. One obvious approach would be to reduce the duration of standard tows, thus decreasing the time the fish are in the codend. This would also reduce the quantity of fish in the codend, ensuring that delicate species such as megrim are impacted less by ‘rough’ species. However, the current duration of tows is possibly adapted to the optimum for the main target species, anglerfish, which is a relatively robust fish and is not subject to the same levels of damage in the codend. Furthermore, a reduction in tow duration would result in more of the fishermen's time, within a limited effort system, spent hauling and shooting the gear. Given the financial implications of this, it may be that fishermen are opting to accept the loss of bruised fish in a species such as megrim in order to maximise their returns for the principal species, in this case anglerfish. However, this may change with the implementation of a discard ban. This is a further example of the inherent complexities associated with mixed-species demersal fisheries.

The significant difference between sexes in discarding of small fish is most likely to be due to sexual dimorphism, as female megrim are known to grow faster and larger than males (Macdonald *et al.*, 2013). This results in a larger proportion of males being present in smaller size classes. Furthermore, 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 would have the potential to cause distortion in the stock assessment process if the assessment was done by sex, especially as the assessment for megrim in IVa currently lacks in accurate discards data. Therefore, the introduction of a discard ban or catch quota management system has the potential to provide more accurate data for the assessment process.

For a number of species, total fishing mortality, including the discarded portion of the catch, is accounted for in the assessment and management process (Fernandes *et al.*, 2011). However, for species such as megrim, incomplete data sets prevent an accurate estimate of fishing mortality (ICES, 2012a). This lack of data restricts the ability to undertake accurate assessments and may ultimately lead to mismanagement of the stock. Further, ICES have proposed that a Precautionary Buffer consisting of a 20% reduction to catch advice should be applied when stock reference points are unknown (ICES, 2012b). In the mixed demersal fishery in the northern North Sea, where stock reference points for many of the less significant commercial species are unknown, this may have the effect of considerably reducing TAL but it is unclear how the approach will reduce total catches and lead to improved management. Indeed, in the absence of effort restrictions it may be that the Precautionary Buffer approach does little to improve the management of the stock but will rather lead to increased discarding and continued or increased uncertainty of fishing mortality. However, following the implementation of the Precautionary Buffer, exceptions to this rule have resulted in some cases where there has been evidence that a given stock size is increasing or exploitation has reduced significantly (ICES, 2013b).

Fishing effort in the mixed species demersal fishery in the northern North Sea is primarily driven by available TAC for the principal target species. Therefore, given the scenario of limited TAC for an abundant species in the target assemblage and adequate TAC for the principal targeted species, discarding of the secondary species will persist as fishing for the target species continues. This is indeed the case in the northern North Sea where megrim catches are typically a byproduct of the effort expended targeting anglerfish. This scenario serves to question the validity and efficacy of a TAL for a predominantly bycatch species such as megrim. In this instance the TAL system does little to regulate fishing mortality, and simply determines the amount of fish that is accounted for in landings. This is one of the major shortcomings of the CFP which it is anticipated will be amended in the CFP reform (Anon, 2011c).

Under the proposed reform of the CFP it is anticipated that a number of legislative measures will be implemented with the aim of improving management of fish stocks in EU waters. These include a discards ban, a bid to manage stocks according to maximum sustainable yield (MSY) and the regionalisation of fisheries management (Anon, 2011c). While the need for measures to improve resource management is widely accepted, there have been concerns among fishermen about the practical implementation of various aspects of the reformed CFP (Shetland Fishermen’s Association, pers. comm.). Gear innovation has also been advocated as an important aspect of the MSY approach, with the aim of developing fishing gear that has improved selectivity (Anon, 2011b) and allows over-exploited or undesirable species to escape. While this has proven successful for some species and fisheries, there are examples where species selection, in terms of selecting for all desirable species, has proven difficult (Kynoch *et al.*, 2011).

Given the complex nature of mixed fisheries, the implementation of an ecosystem-based approach, incorporating multispecies modelling, is being developed and advocated as a means to account for direct and indirect ecological interactions among species and their environment (Latour *et al.*, 2003). Hollowed *et al.* (2000) noted that multispecies interactions need to be placed within the context of numerous other factors and processes influencing the system and that many current models only address a subset of these factors. The move towards an ecosystem approach within the northern North Sea mixed fishery is, while desirable, potentially a long way off due to a lack of information on rudimentary factors such as the ecology of many of the key species that make up the fishery.

Conclusion

Levels of megrim discarding in the northern North Sea have decreased significantly in recent years, primarily as a result of an increase in vessel specific quotas. 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 also indicate that discarding of megrim may continue in future years under the current TAC. The current megrim TAC does little to regulate fishing mortality in the mixed demersal fishery and serves only to regulate landings. Furthermore, the proposed reform of the CFP, including the move towards the implementation of MSY, raises a number of concerns that need to be addressed if the fishery is to be managed sustainably and continue to be economically viable in the future.

Acknowledgements

This study was carried out during a wider investigation into the biology, ecology and fishery of megrim in the northern North Sea and was partly funded by the Seafish Industry Authority, Scottish Fishermen's Trust and Shetland Islands Council. We are grateful to the Shetland Fishermen's Association and all the fishermen and who provided access to their vessels for sampling. We are also grateful to Sarah Kraak, Jordan P. Feekings and two anonymous reviewers for insightful comments that have greatly improved the manuscript.

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Table 1 Summary of number of vessels and hauls sampled, annual quota allocation and composition of megrim discards from 2008-2012 in the northern North Sea.

		Twin trawl		Seine						
Year	Sampling Months	Trips sampled	Total hauls	Trips sampled	Total hauls	Quota allocation for IV and IIa (‘000 tonnes)	Number discarded	Proportion small	Proportion bruised	Proportion below MLS
2008	May - October	5	98	1	22	1.59	7187	0.33	0.13	0.0095
2009	June - August	2	34			1.59	1857	0.39	0.15	0.0005
2010	May - December	5	71	2	21	1.75	3661	0.36	0.15	0.0003
2011	January - September	6	112			1.845	3604	0.25	0.12	0.0044
2012	January - February	4	49			1.845	692	0.10	0.10	0.0014

Table 2 Results for individual model covariates.

Total discards (r^2 = 0.40)				**Small discards (r^2 = 0.71)**				**Bruised discards (r^2 = 0.16)**			
Variable	Coefficient	SE	*P*-value	Variable	Coefficient	SE	*P*-value	Variable	Coefficient	SE	*P*-value
Intercept	-1.84	0.97	0.06	Intercept	-3.22	1.76	0.069	Intercept	-2.15	0.23	<0.001
Length	-0.27	0.01	< 0.001	Length	-0.79	0.01	< 0.001	Length	0.06	0.003	< 0.001
Quota	-0.97	0.21	<0.001	Quota	-0.36	0.32	0.27	Quota	-0.25	0.08	0.004
Sex (M)	-0.12	0.10	0.12	Sex (M)	-0.29	0.12	0.02	Sex (M)	0.05	0.09	0.89
Wind Strength	0.06	0.02	<0.001	Wind Strength	0.16	0.02	< 0.001	Wind Strength	-0.03	0.02	0.11
Length×Sex	-0.13	0.03	<0.001	Length×Sex	-0.06	0.02	0.002	Length × Sex	0.14	0.003	<0.001
Length×Quota	0.006	0.003	0.09	Quota×Wind	-0.18	0.02	<0.001	Length× Quota	-0.02	0.00	<0.001
Quota×Wind	-0.05	0.01	<0.001								

n = 37403, 19 Trips, 15 Vessels, 7 Stat Squares. *P*-values for the intercept denote whether the intercept was different from 0.5. Standard error (SE) is also shown.

Table 3 Variance associated with random effects for individual models.

	Intercept variance		
Random term	**Total discards**	**Small discards**	**Bruised discards**
Vessel	0.56	1.95	0.53
Trip nested in Vessel	0.25	2.46	0.10
Stat Square	0.20	0.89	0.10
Year	0.79	1.01	0.06
Month	1.09	4.56	0.04

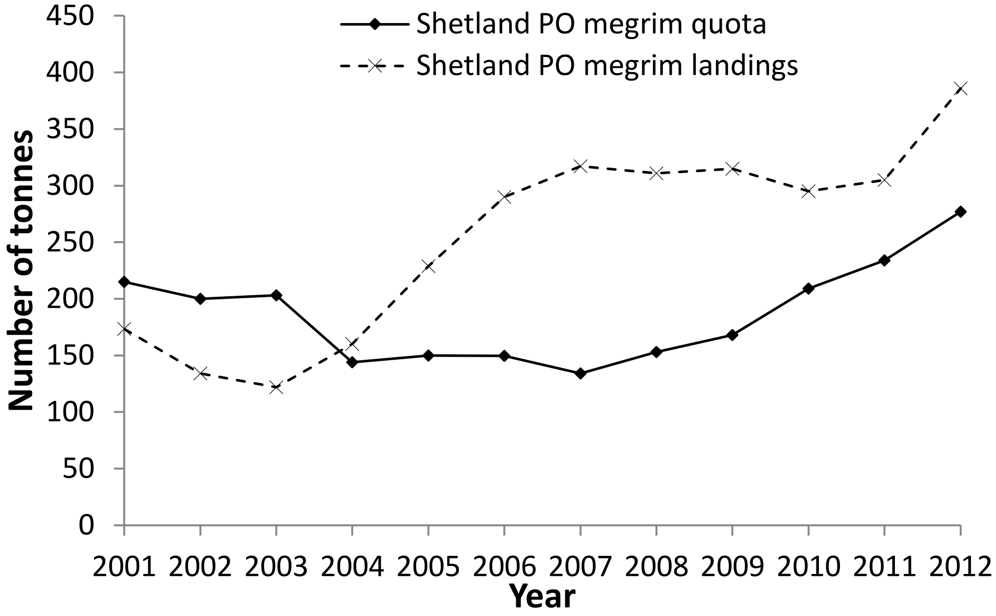


Figure 1 Annual megrim quota allocation and uptake for the Shetland Fish Producers' Organisation from 2001-2012 (Data source: Shetland Fish Producers' Organisation).

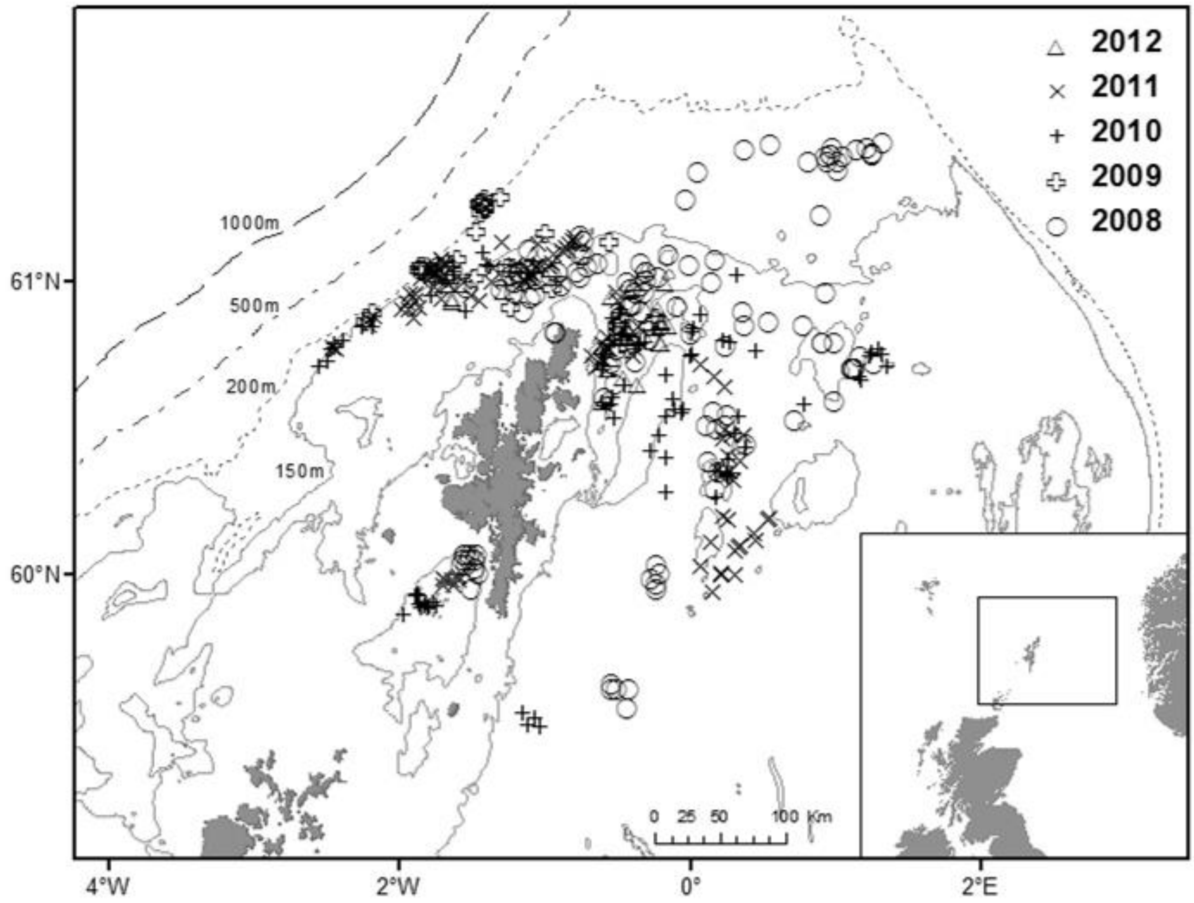


Figure 2 Map of study area within ICES Division IVa with the location of individual fishing hauls from 2008-2012 highlighted.

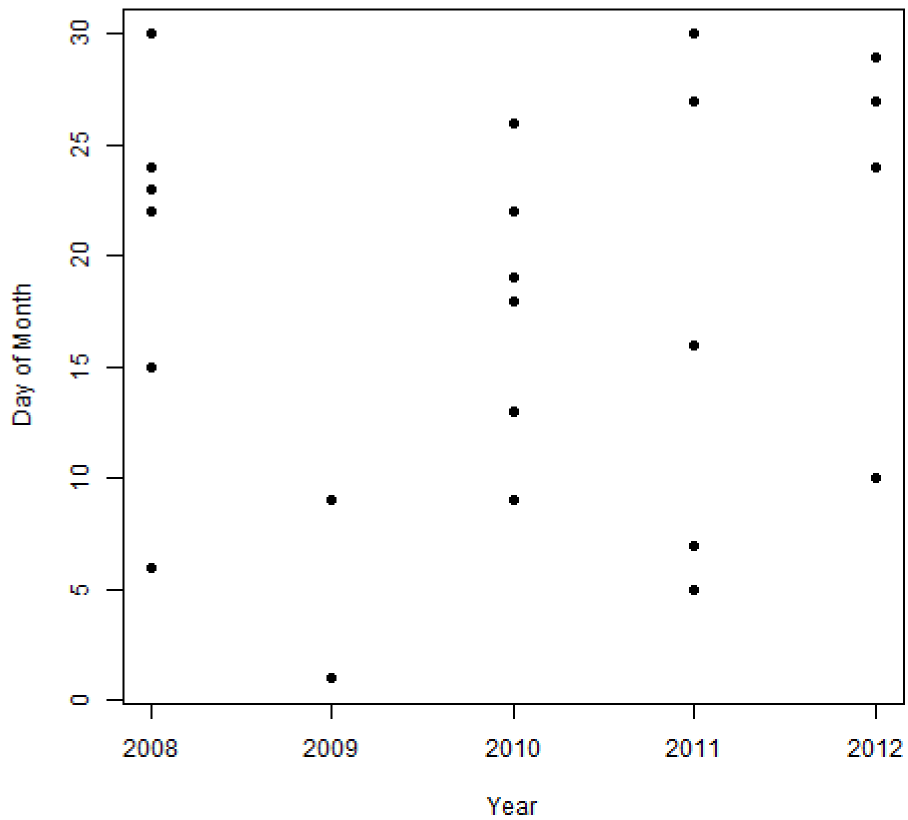


Figure 3 Day of the month in which each observer trip began for each of the five years during the study period.

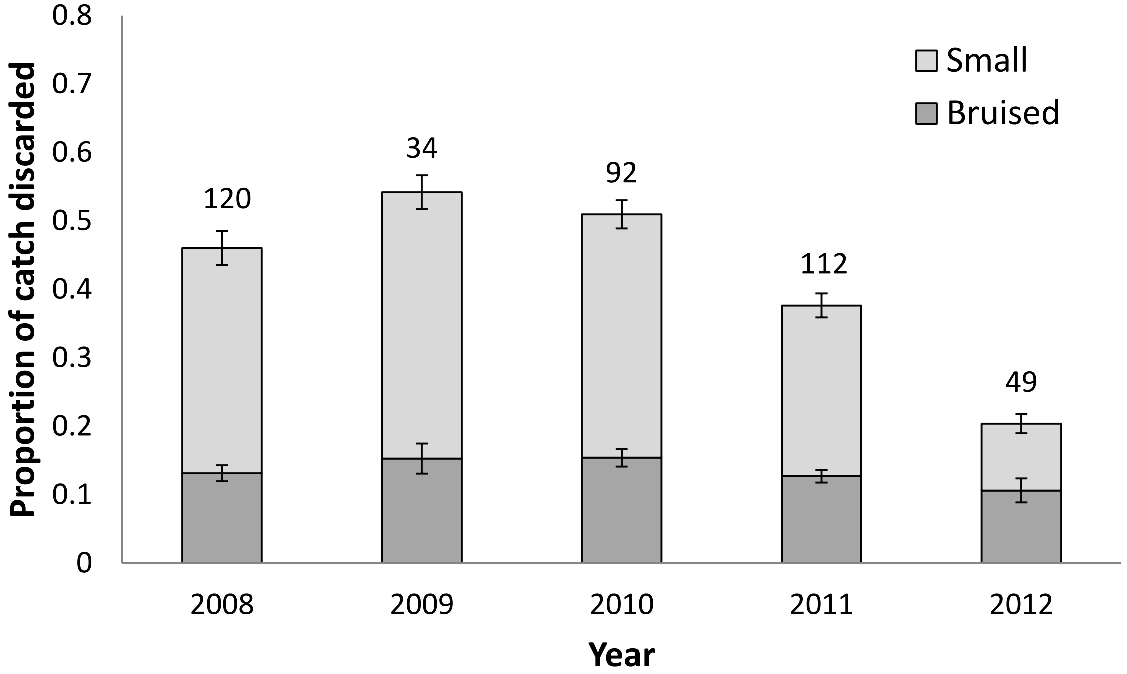
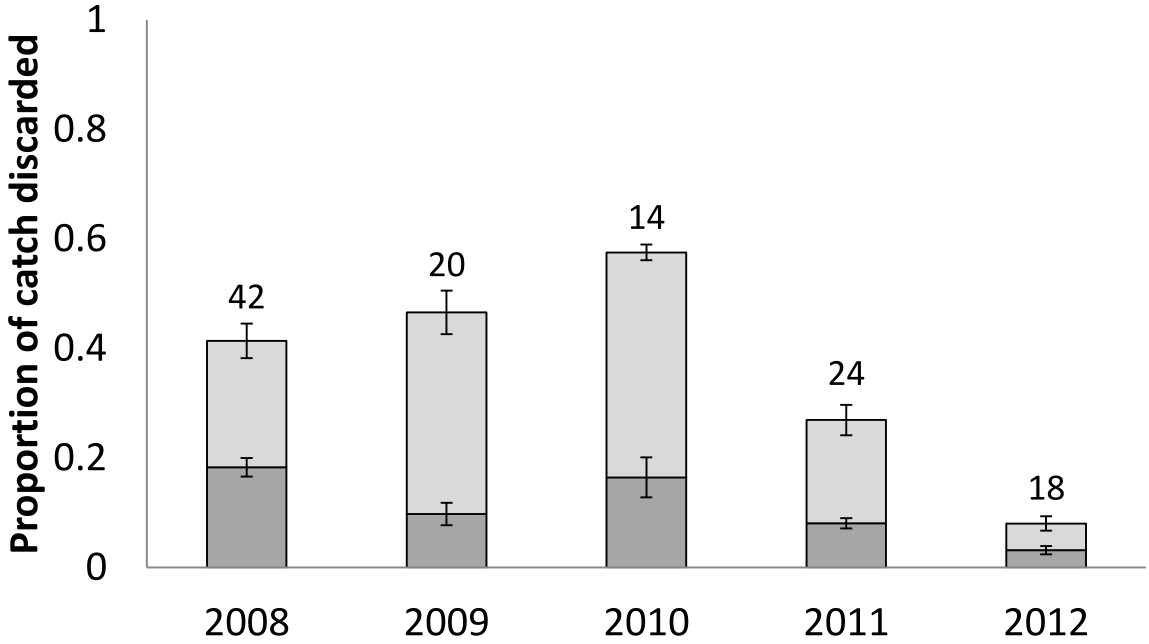
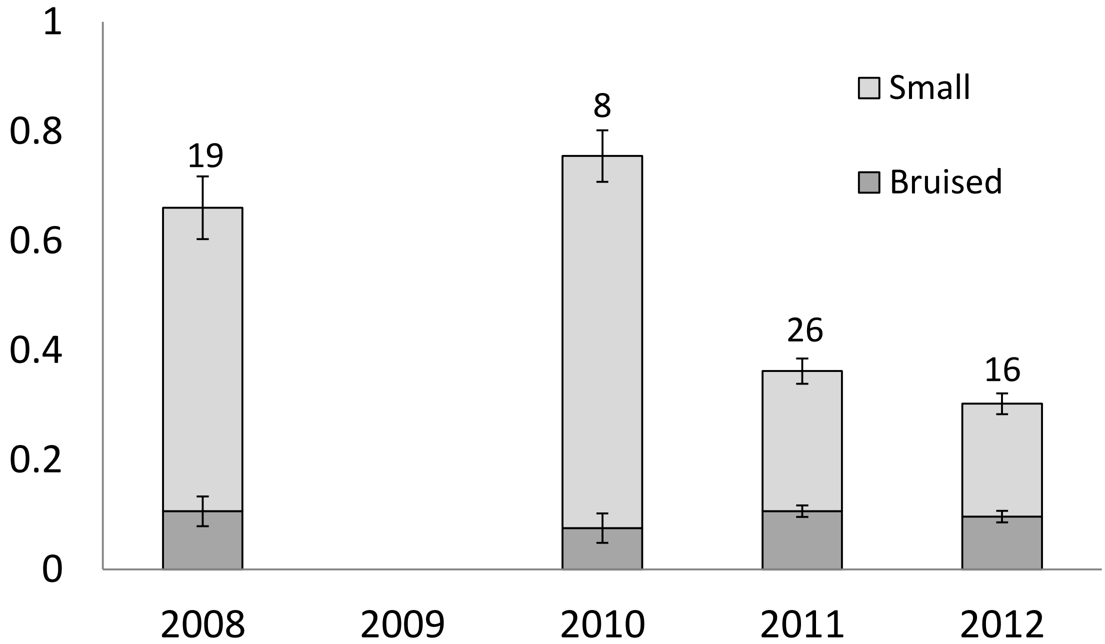


Figure 4 Average composition of *L. whiffiagonis* discards per haul for all vessels. ± s.e. bars and total number of hauls are also shown.


Proportion of catch discarded
1
0.8
0.6
0.4
0.2
0
42
20
14
24
18
2008
2009
2010
2011
2012


1
0.8
0.6
0.4
0.2
0
Small
Bruised
19
8
26
16
2008
2009
2010
2011
2012

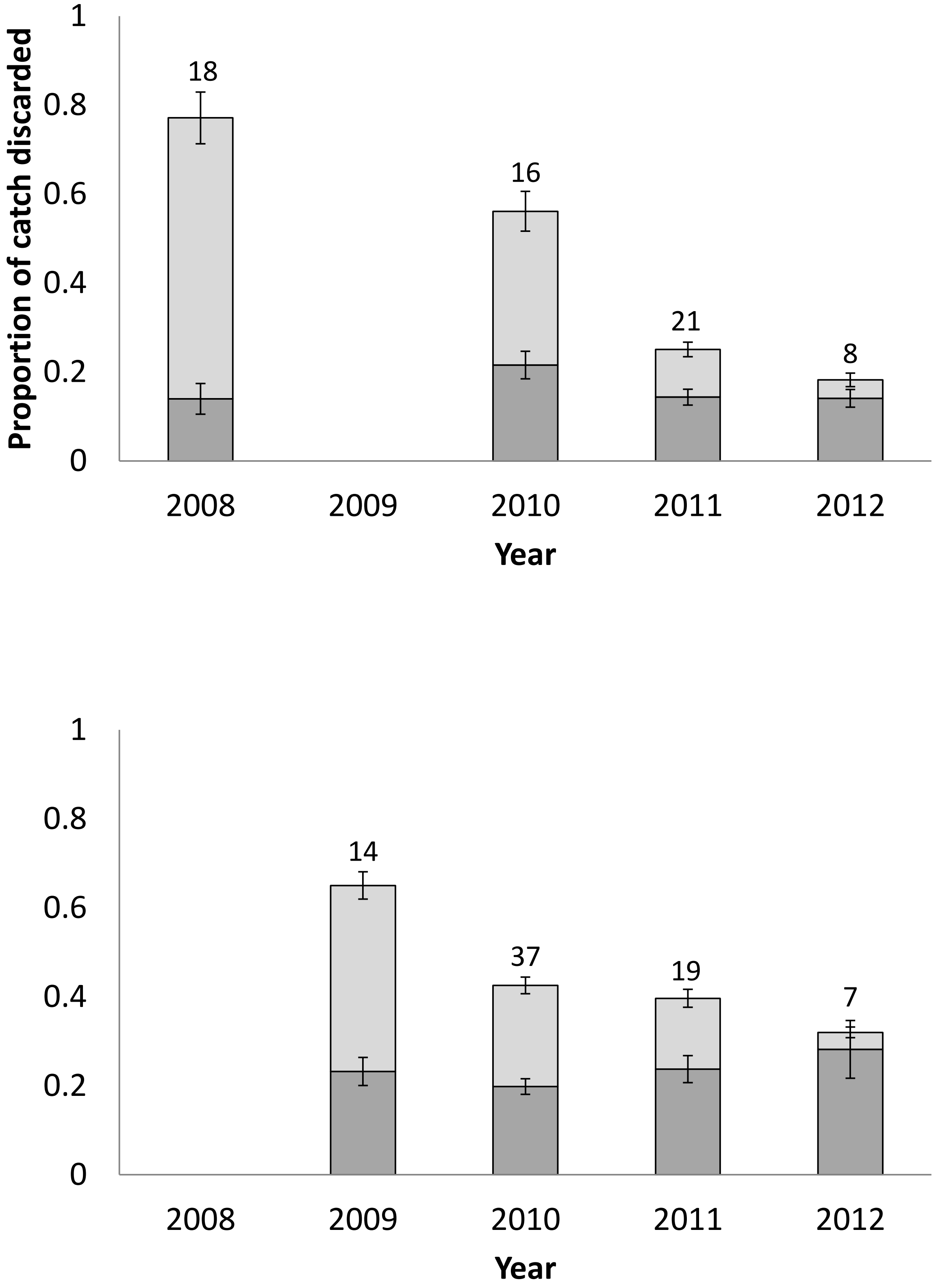


Figure 5 Average composition of *L.whiffiagonis* discards per haul for the four most regularly sampled individual twin trawl vessels. ± s.e. bars and total number of hauls are also shown.

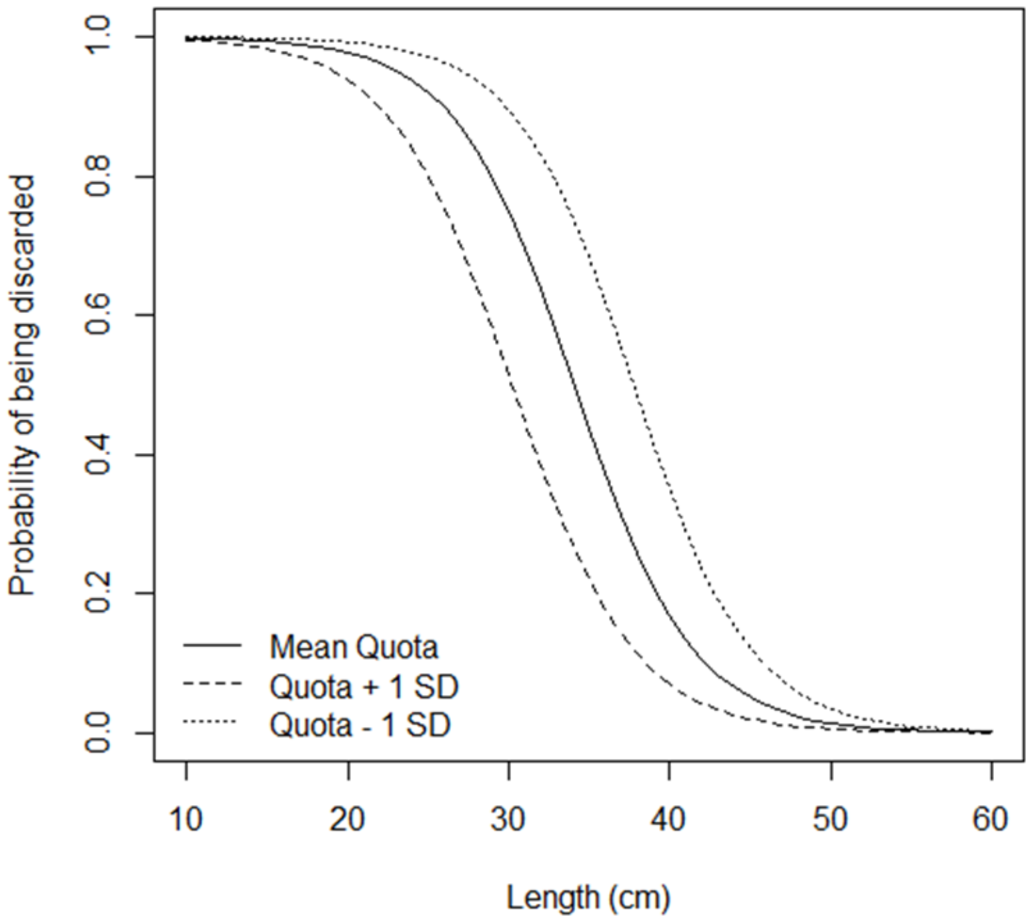


Figure 6 Relationship between length and the probability of being classed as a discard as quota increases. (Predicted curves from the model when quota is at its mean value as well as 1 standard deviation (SD) above and below the mean; Mean Quota = 531 kg, SD = 294 kg, curves are plotted with everything else in the model held constant).

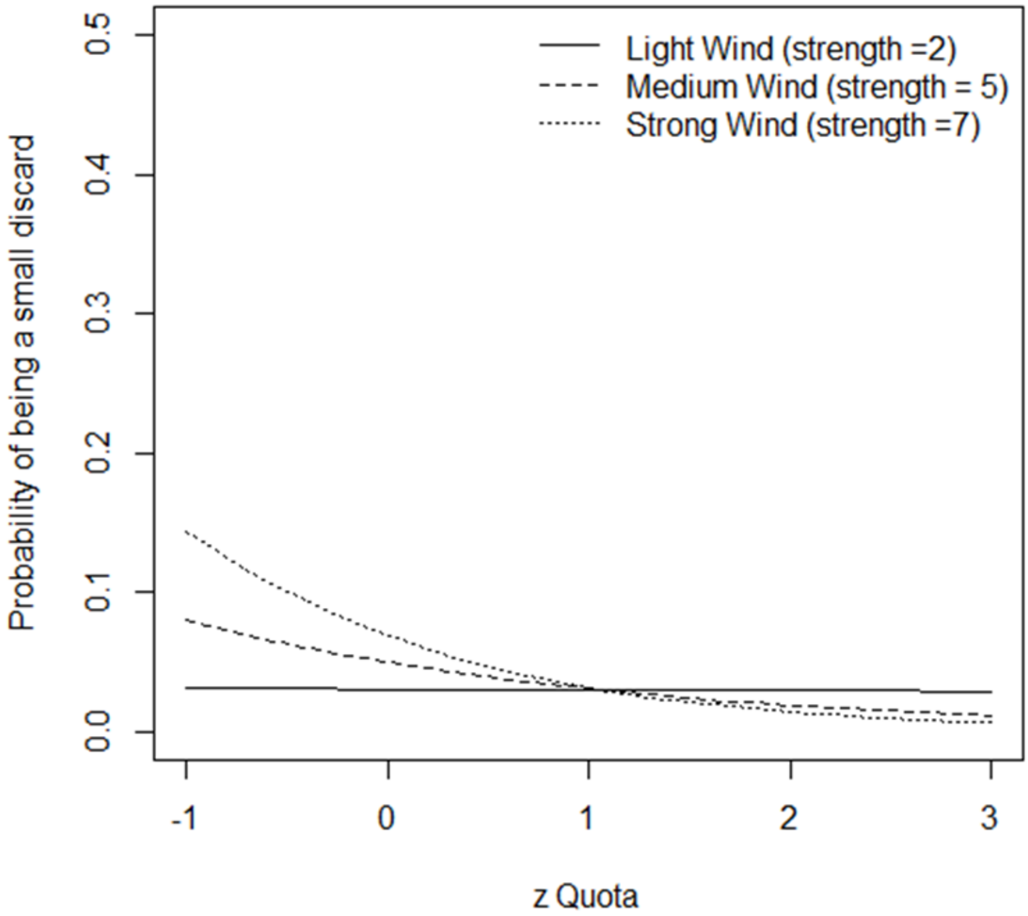


Figure 7 The effect of standardized Quota (z Quota) and Wind Strength on the probability of a fish being classed as a small discard. (Standardized Quota is plotted on the x-axis with 0 representing the mean Quota (531 kg) across the study period. The units of standardized Quota can be taken as standard deviations from the overall mean. In order to display the interaction three different Wind Strengths were chosen).

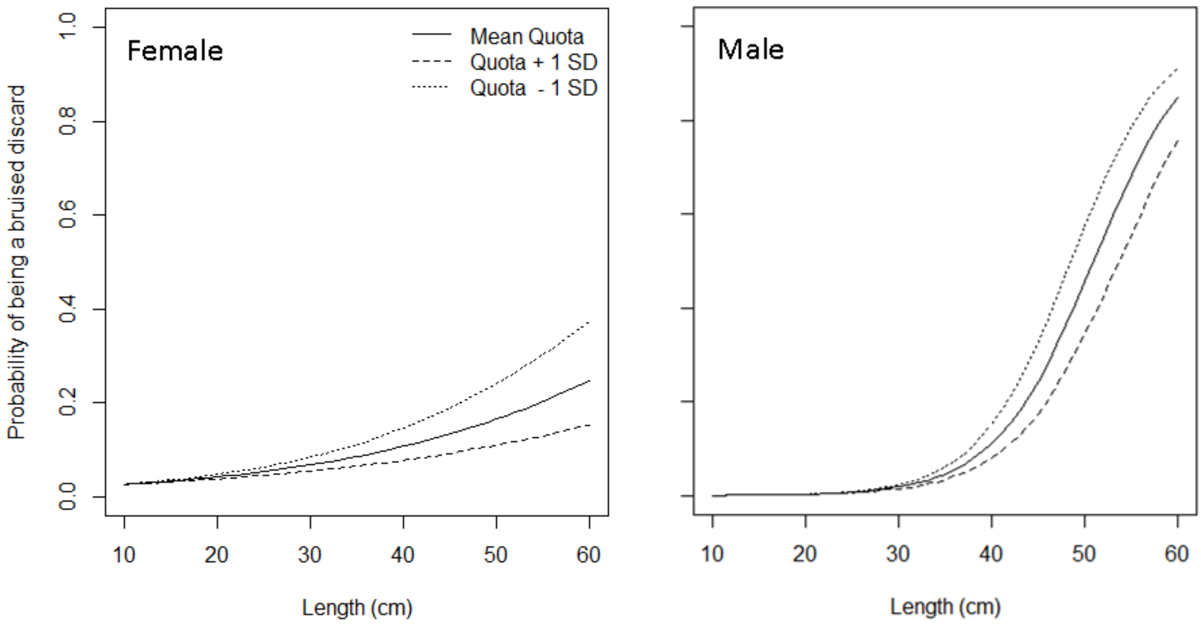


Figure 8 The effect of Length and Quota on the probability of being classed as a bruised discard for female and male megrim. (In order to display the interaction, three different values for Quota are shown; the mean value across the study as well as + 1 SD and – 1 SD).