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**BANGOR**  
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**The Isle of Man *Aequipecten opercularis* fishery  
stock assessment 2013**

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***Preface***

The Isle of Man's queen scallop fishery has been dependent largely on annual recruitment over the past 20 years. Due to the limitations of available data the report does not provide an exact total allowable catch. However, advice is provided, based on landings and survey data, which aims to prevent biomass being severely depleted and to reduce the dependence of the fishery on each year's recruitment. The report is intended to provide guidance to the fishing industry and the Isle of Man Government.

## Summary

A fishery for queen scallops, *Aequipecten opercularis*, has been prosecuted in and around the Isle of Man's territorial sea since the 1950s, becoming of increasing importance during the late 1960s. Until recently queen scallops were targeted almost entirely with either toothed dredges or skid dredges. However, most Manx vessels now fish for queen scallops with otter trawls, while UK vessels usually use toothless dredges. The trawl fishery commences in June each year, thus the queen scallop fishing year is taken to run from June to May the following year.

A precautionary management strategy for the Isle of Man's queen scallop fishery was set out in 2010 and reviewed by a Marine Stewardship Council (MSC) assessment team. The trawl fishery was MSC certified in May 2011, while the dredge fishery failed to meet the necessary standard due to the negative impact of dredging on benthic habitats. A key aspect of ensuring the sustainability of the fishery is that management responds to stock status and that the impact of the fishery on the seabed remains limited.

Queen scallop abundance increased sharply in the Isle of Man's territorial sea between 2007 and 2010. This increase, combined with strong market demand, led to increased fishing effort and landings of queen scallop in 2010 and 2011. Over 65% of landings were taken by UK dredgers in 2010 and 2011, with otter trawlers taking 20-24% of landings. By comparison, within the territorial sea in 2012 otter trawlers caught around 63% of total landings, with dredgers taking 68% of landings across ICES rectangles 36E5 and 37E5.

The first formal stock assessment of the Isle of Man queen scallop stock was undertaken in 2012 using the Catch-Survey Analysis (CSA) method. The CSA method estimates stock size using abundance indices and is generally well-suited to the data available for the Isle of Man's queen scallop fishery. The stock assessment showed that the biomass of recruits and post-recruits declined from 2010 to 2012. Total biomass was estimated to have declined by over 16000t between 2010 and 2012. It is estimated that over 40% of total biomass was removed between June 2010 and May 2011. Landings in 2012 were lower than in 2011, at 8000t, and fishing mortality decreased.

It is recommended that no more than 30% of biomass is removed in any year to minimise the risk of queen scallop biomass depletion; in 2013/2014 this equates to 6000t. However, given recent biomass depletion a precautionary limit of 5000t (25% of biomass) is advised for the 2013/2014 season. Biomass is very likely to be depleted leading to the fishery becoming recruitment-dependent where >40% of biomass is removed annually.

## 1. Background

### 1.1 The fishery

A fishery for queen scallops, *Aequipecten opercularis*, has been prosecuted in and around the Isle of Man's territorial sea since the 1950s, becoming of increasing importance during the late 1960s. Until recently queen scallops were targeted almost entirely with either toothed dredges or skid dredges. However, most Manx vessels now fish for queen scallops with otter trawls, while UK vessels use toothless dredges. The fishery within the territorial sea is governed by several management measures that include areas where dredging is prohibited, a closed season and a minimum landing size (Sea-Fisheries Act 1971. Isle of Man Sea-Fisheries (queen scallop fishing) bye-laws 2010. Statutory document No. 668/10). Outside of the territorial sea the fishery is subject to very few management measures.

### 1.2 Marine Stewardship Council certification

A precautionary management strategy for the Isle of Man's queen scallop fishery was set out in 2010 and reviewed by a Marine Stewardship Council (MSC) assessment team (Andrews *et al.*, 2010). The trawl fishery was MSC certified in May 2011, while the dredge fishery failed to meet the necessary standard due to the negative impact of dredging on benthic habitats (Hinz *et al.*, 2011). A key aspect of ensuring the sustainability of the fishery is that management responds to stock status and that the impact of the fishery on the seabed remains limited. Certification of the fishery was made on the basis of nine conditions being met over various timescales and the actions required to meet these conditions were set out in an action plan (Bangor University/DEFA, 2011). These conditions include developing a habitat management strategy and undertaking a formal stock assessment.

### 1.3 Recent increases in fishing effort

An increase in the demand for queen scallops in 2010 prompted discussions about the management of the fishery. A meeting between relevant attendees of the UK National Scallop Group was held on 29<sup>th</sup> June 2011 in Manchester to discuss concerns over high fishing pressure on queen scallops in the Irish Sea. The possibility of a need for voluntary measures to manage the fishery was raised. A second meeting, held between the Seafish Industry Authority (Seafish) and several scallop processors in Preston on 21<sup>st</sup> July 2011, identified an increase in demand for queen scallops combined with increased catching capacity.

### 1.4 Stock assessment

A stock assessment of the Isle of Man queen scallop stock was undertaken using the Catch-Survey Analysis (CSA) method, first developed by Collie and Sissenwine (1983), the results of which are presented by Murray and Kaiser (2012). The CSA method estimates stock size using abundance indices and is generally well-suited to the data available for the Isle of Man's queen scallop fishery. The method is currently used in the Gulf of Maine shrimp fishery (Cadrin *et al.*, 1999; Idoine, 2006). Comparisons of CSA with a surplus production model (ASPIC) were favourable although particular care is needed in correctly identifying recruits and post-recruits (Cadrin, 2000). CSA has been advocated as a valuable method to support management advice where age data is not available (Mesnil, 2003). Absolute estimates of stock size and fishing mortality derived from CSA are sensitive to input parameters, although trends over time are more robust to changes in these input

parameters (Mesnil, 2003). In 2012, it was recommended that no more than 5000t be taken from ICES rectangles 36E5 and 37E5 to reduce the risk of biomass being depleted (Murray and Kaiser, 2012b) and, preferably, allow an increase in biomass.

## 2. Methods

### 2.1 Scallop surveys and abundance index

Despite surveys of the Isle of Man's scallop populations having been undertaken biannually (typically in June or October) since 1992 (Beukers-Stewart *et al.*, 2003) most survey stations (Fig. 1) have been visited intermittently, although latterly with increased sampling effort. Survey station name abbreviations are: Bradda Inshore (BRI), Bradda Offshore (BRO), Port St. Mary (PSM), Chickens (CHI), South East of Douglas (SED), East of Douglas (EDG), Laxey (LAX), Ramsey (RAM), Point of Ayre (POA), Peel (PEL) and Targets (TAR). In 2012 and 2013 sampling effort was increased to include stations across the extent of the queen scallop stock within the territorial sea (Fig. 1). Stations that were sampled in both 2012 and 2013 (3, 8, 9, 14, 20, 21, 22, 23, 24, 25, 29, 32, 34, 35, 38 and 39), in addition to the standard survey stations, were included in the stock assessment. Stations in ICES statistical rectangle 38E5 (and landings from this area) have not yet been included in the assessment since this area was not surveyed before 2008 and only a single station has been sampled in most years since then. Stations were surveyed using the protocol described by Hinz *et al.* (2009) and Murray *et al.* (2009).

Failing to down-weight isolated high-density patches of scallops would increase the risk of over-estimating population size (Hutchings, 1996). Therefore, the geometric mean, calculated across survey stations, was used to derive the abundance indices. This was precautionary and necessary to obtain meaningful stock assessment results.

This year RV Prince Madog was available only in February; therefore, the most recent survey was conducted in February 2013, which is earlier in the year than is usual. Given that the minimum annual temperatures occur around March it is likely that growth and predation will have been low during the months between February and May (when surveys would usually be undertaken). Therefore, it was assumed that the early survey will have had minimal impact on catches. The dredges used in the surveys have a belly ring internal diameter of 55 mm and thus under-sample smaller queen scallops. To assess the gear selectivity of dredges a 2 m beam trawl, with cod end mesh size of 4 mm and an outer net with a 10 mm mesh, was used at RAM and LAX stations in May 2011. Five tows were made at each station with the beam trawl alongside three tows at each station with the queen scallop dredges. The proportion of scallops in each size class caught in the dredge relative to the beam trawl was used to estimate the gear selectivity of recruits relative to post-recruits. The mean proportion of recruits (<55 mm) retained relative to the proportion of fully recruited animals was used in the stock assessment. A gear selectivity curve was also calculated. Length ( $L$ ) was plotted against  $\log_e((1-P)/P)$  to determine the constant  $-r$ , where  $\log_e((1-P)/P) = rL_c - rL$  and  $P = 1/(1 + e^{-r(L-L_c)})$  allowing the proportion retained,  $P$ , in each size class to be estimated.

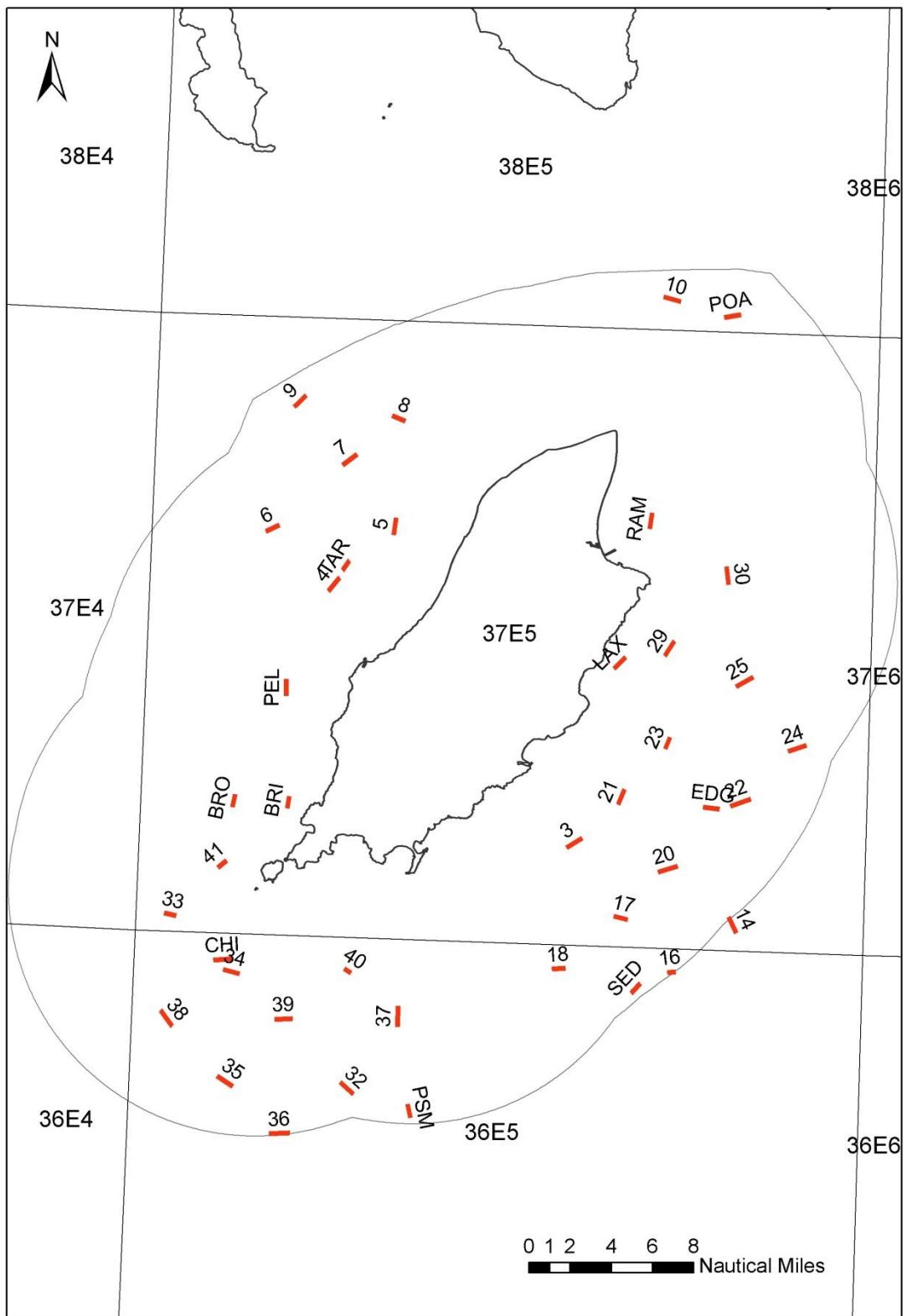


Fig. 1. Survey stations around the Isle of Man. Numbered stations were first sampled in 2012 and 2013.

Work undertaken in 2008 and 2011 revealed discard mortality to be low at between 3% and 9% of catches by a trawler and two dredgers fishing around EDG and SED stations (Nall, 2011). Duncan (2009) estimated discards of 21% from 11 different trawlers. The quantity of discards will be a function of the number of under-sized scallops in the population but importantly discard mortality was found to be low (Montgomery, 2008; Nall, 2011). Montgomery (2008) recorded no mortality in queen scallops maintained in aquaria for two-weeks after trawling, although there was a reduction in escape response suggesting a higher risk of predator induced mortality. Nall (2011) recorded mortality rates of 10 to 19% in queen scallops maintained in shrimp creels at sea for 10 days. Based on these figures we assumed a mean discard mortality rate equivalent to 2% of the weight landed. However, *in situ* mortality resulting from interaction with fishing gear is unknown.

### Stock assessment

The stock assessment was implemented using CSA v3.1 (NOAA, 2008). Data from the spring surveys was used since this is when temperature is lower and dredges are a more effective means of sampling queen scallops (Jenkins *et al.*, 2003), and before the main queen scallop fishing season. The stock assessment unit is the area covered by ICES statistical rectangles 36E5 and 37E5, which includes the majority of the fishing grounds. Furthermore, historical landings data cannot be resolved to the Isle of Man's territorial sea and landings data from the United Kingdom up to the end of 2010 was available to us for these ICES statistical rectangles only.

Abundance indices were derived from survey data from 1993 to 2013. Data from 1992 was not included in the assessment since only two stations were surveyed in this year, one of which was only surveyed until 1997. The geometric mean across survey stations was used to obtain abundance indices of recruits and post-recruits (fully-recruited individuals). A geometric mean was used in order to down-weight stations with very high abundance and is a more precautionary index than the arithmetic mean.

In the CSA model, the population dynamics of the fishery are described by a process equation using the population size of two size classes of queen scallops: fully recruited,  $N$ , and recruits,  $R$ :

$$N_{t+1} = (N_t + R_t)e^{-M} - C_t e^{-M(1-\tau)} \quad (1)$$

where  $t$  is an annual fishing year and  $C$  is the catch in numbers;  $\tau$  is the proportion of the year over which landings are taken and  $M$  is natural mortality. Population estimates of post-recruits and recruits are derived from survey relative abundance indices:

$$n_t = q_n N_t e^{\eta t} \quad (2)$$

and

$$r_t = q_r R_t e^{\delta t} \quad (3)$$

where  $n_t$  and  $r_t$  are abundance indices of fully recruited queen scallops and recruits;  $q_n$  and  $q_r$  are the catchability coefficients of the queen scallop dredges used in the annual surveys. The terms  $e^{\eta t}$  and

$e^{\delta t}$  are log-normal random measurement errors. Catchability of recruits was defined as a proportion,  $s$ , of fully recruited queen scallops:

$$s = \frac{q_r}{q_n} \quad (4)$$

Fully recruited queen scallops were considered to be those of  $\geq 55$  mm length; thus, catches were assumed to consist of scallops  $\geq 55$  mm with sizes in proportion to survey average size frequency distributions. Average individual weights of recruits were derived from the relationship between length and weight measurements of 600 queen scallops from stations across the territorial sea. Historically, 50 to 55 mm has been considered the minimum commercially viable size (Brand, 2006). At present, dredgers typically use belly-rings of 60 mm internal diameter while trawlers use a cod-end with mesh of 80 to 90 mm. Therefore, catches of queen scallops  $< 55$  mm are likely to be low, and these smaller scallops remain commercially less desirable. Recent research found almost no landings  $< 55$  mm in either dredgers or trawlers (Nall, 2011). Allison (1993) fitted Von Bertalanffy Growth Functions (VBGF) to length at age data of queen scallops from around the Isle of Man. Mean growth rate expressed as VBGF parameters were  $L_\infty = 75.91$ ,  $k = 0.59$  and  $t_0 = -0.88$ . This equates to approximately 30 mm growth for a scallop of 27.5 mm during 1 year. Therefore, recruits were considered to be queen scallops 25 to 54 mm length. However, the smallest size of scallops caught were 25 mm and these were rare; therefore, the recruitment index was in effect scallops between 30mm and 55mm. Allison (1993) used six different methods to estimate natural mortality,  $M$ , all yielding different results ranging from 0.037 to 1.88 but identified values of 0.2 to 0.5 as most appropriate. The effects of using values of  $M$  between 0.2 and 0.4 were examined in an earlier report (Murray and Kaiser, 2012). Based on this earlier work this present stock assessment uses  $M = 0.2$  and  $s = 0.35$ . It is important to note that biomass and mortality estimates relate only to recruits and fully-recruited scallops not to scallops  $< 25$  mm.

The harvest rate ( $h$ ) was calculated using the equation:

$$h = \frac{C_t e^{TM}}{R_t + N_t} \quad (5)$$

Fishing mortality was then estimated as  $F = -\ln(1-h)$  following Collie and Kruse (1998). However, there is no advantage in using this estimate of  $F$  instead of the harvest rate to set management thresholds and both show the same patterns with time (Mesnil, 2005). The harvest rate is calculated based on population estimates in numbers. Confidence intervals of harvest rate, fishing mortality, biomass and abundance were derived using a non-parametric bootstrapping procedure. Randomly drawn residuals were applied to survey indices. Since 5% and 95% confidence intervals may not be reliably estimated with this method (Patterson *et al.*, 2001, Mesnil, 2003), 10% and 90% confidence limits were used (see Cadrin *et al.*, 1999; Mesnil, 2003).

Surplus production was calculated as follows:

$$SP_t = B_{t+1} - B_t + CB_t$$

where,



$SP_t$  = surplus production in year t

$B_{t+1}$  = biomass in year t+1

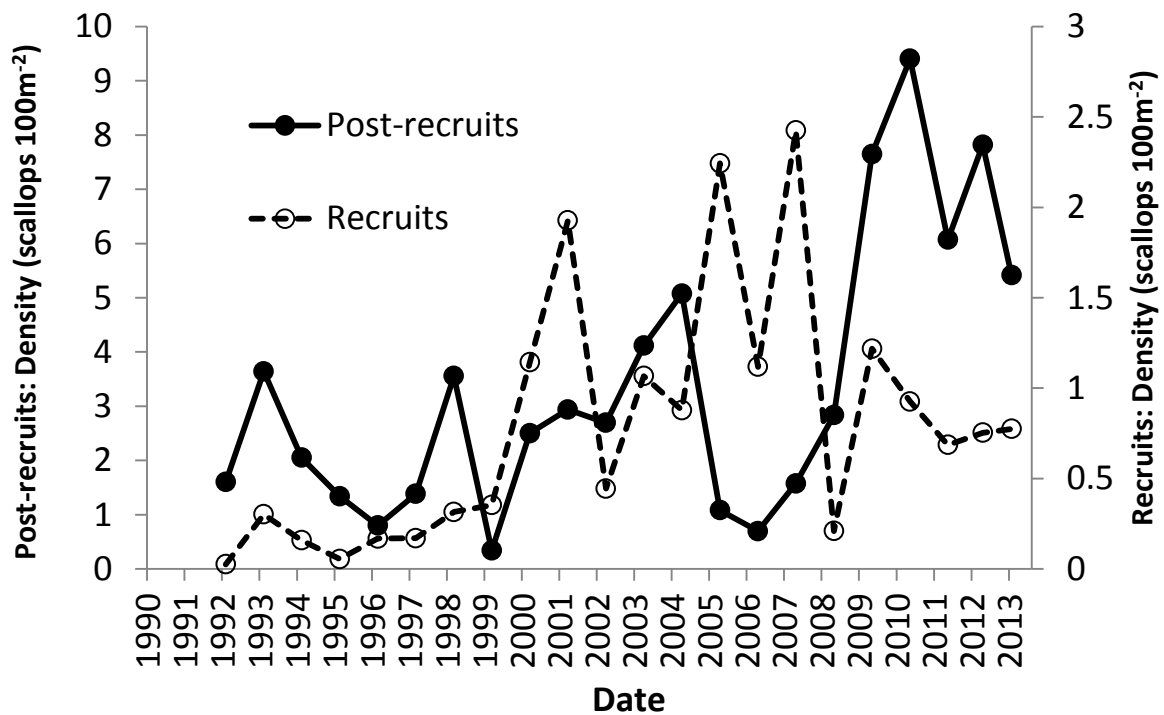
$B_t$  = biomass in year in t

$CB_t$  = catch biomass in year t.

### 3. Results

#### 3.1 Abundance

Mean abundance of recruits has declined each year since 2009 (Fig. 2) while the abundance of post-recruits declined sharply between 2010 and 2011. Post-recruit abundance showed a slight increase between 2011 and 2012 (Fig. 2). From 2006 to 2010 there were year on year increases in post-recruit abundance, with abundance reaching the highest levels on record in 2010.



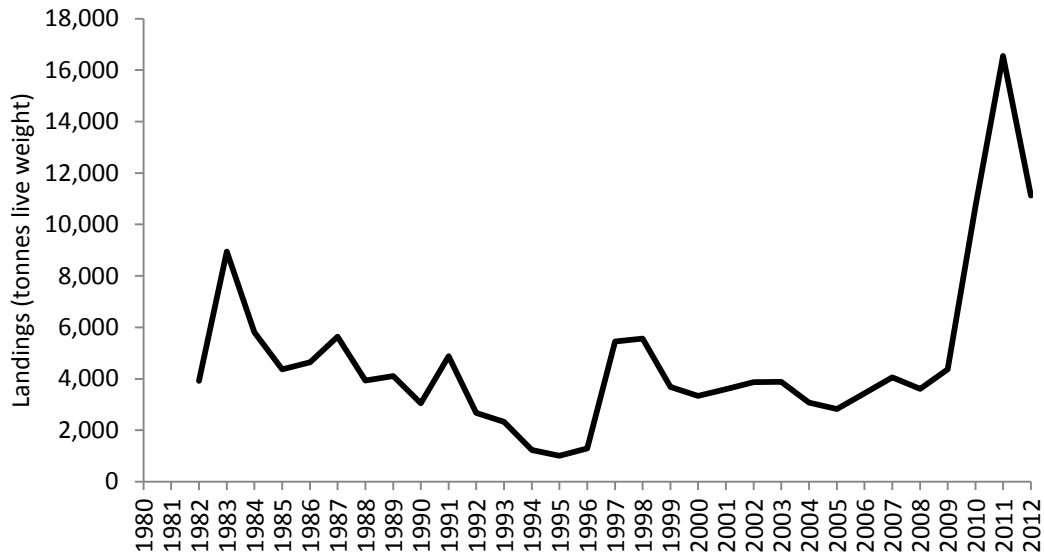
**Fig. 2. Abundance indices for recruits and post-recruits used in the catch survey analysis model**

#### 3.2 Landings and fishing effort

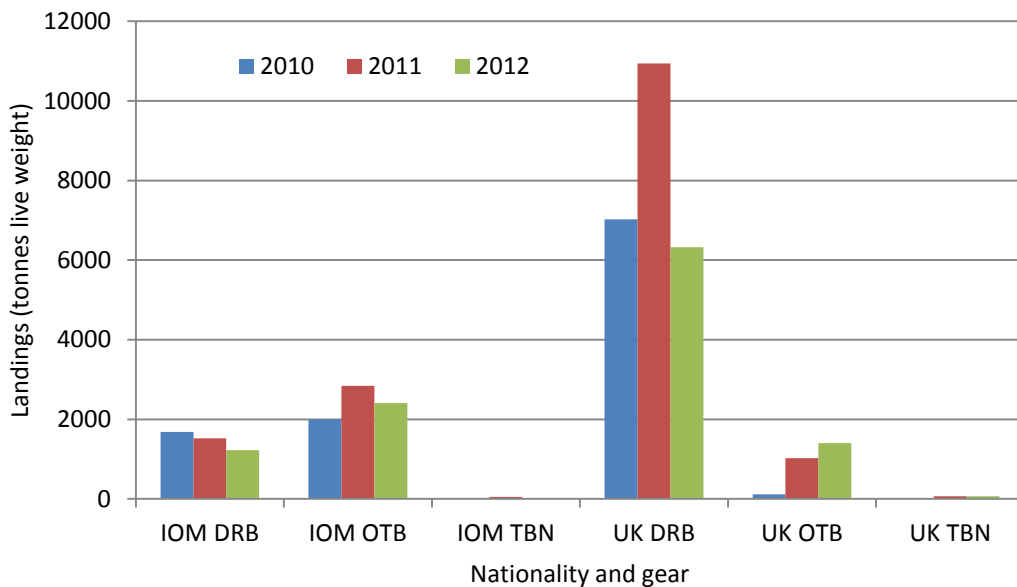
Landings of queen scallops are referenced to ICES statistical rectangles only. Landings from rectangles 36E5 and 37E5 are used as the nearest approximation to landings from the Isle of Man's territorial sea. It is important to note, however, that 36E5 extends south to near Anglesey and that total landings from these two rectangles will be substantially higher than from the territorial sea alone. Landings from Manx vessels in previous years have been spatially referenced to the territorial sea using VMS and logbook data. Logbook data from UK vessels has only recently become available to the Isle of Man for those vessels fishing in ICES rectangles 36E5 and 37E5.

In ICES statistical rectangles 36E5 and 37E5 landings increased between 2010 (Jan. to Dec.) and 2011 (Jan. to Dec.) (Fig. 3 and Fig. 4). By far the greatest increase has occurred due to UK dredgers, with landings increasing from 7028t to 10939t live weight. Manx trawlers also increased landings, from 1998t to 2838t. Manx dredgers decreased landings from 1526t to 1222t. Landings by UK trawlers increased from 106t to 1026t. Queen scallop landings from 36E5 and 37E5 totalled 11398t in 2012, with an additional 572t caught in 38E5. Of the total taken across these three rectangles, 8005t was caught by dredgers, 3884t by otter trawlers, and 80t by *Nephrops* trawls. Landings taken from 36E5 and 37E5 by Manx trawlers represented 18% of total landings in 2010 and 17% in 2011. UK dredgers took 65% of landings in 2010 and 66% in 2011. Manx dredgers took 16% in 2010 and 9% in 2011. Landings of queen scallops from within the territorial sea increased from around 5000t in 2010 to around 8000t in 2011 (Fig. 5). This represents 46% of total landings from 36E5 and 37E5 in 2010 and 49% in 2011. Landings by both dredgers and trawlers increased in the territorial sea between 2010 and 2011, from 3375t to 4673t for dredgers, and from 1559t to 3361t for otter trawlers. The origin of landings in 2012 changed substantially compared to previous years. Within the territorial sea in 2012 otter trawlers caught around 63% of total landings. Outside of the territorial sea dredgers took 95% of landings in 2012. Overall, in 2012, 52% of landings were taken from within the territorial sea, amounting to around 6000t. Fishing effort increased sharply in 2010 and 2011 (Fig. 6) but declined in 2012. However, the number of days spent fishing for queen scallops was still high relative to 2009.

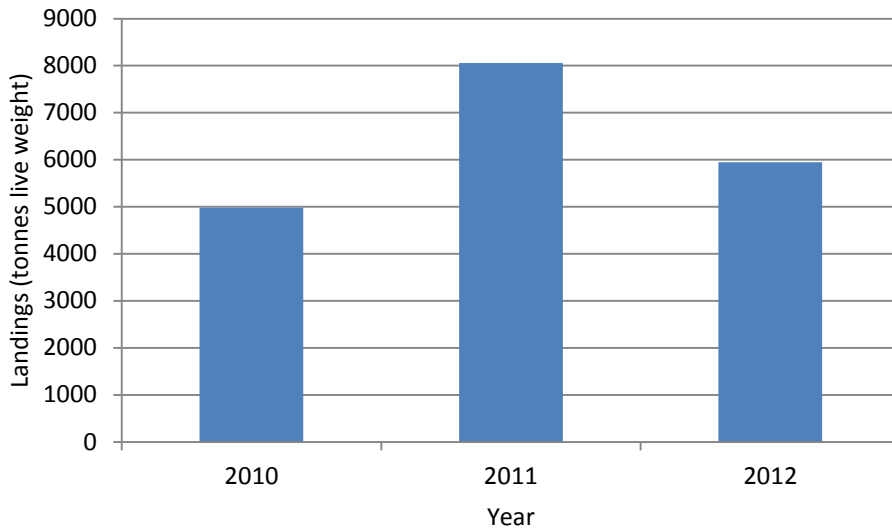
For the stock assessment, landings were estimated from June to May up to 2008, and calculated thereafter, to allow a TAC to be advised from June each year (as is required by the Isle of Man Government). Only annual landings data were available up to 2008. Due to the consistent level of landings over the period from 2000 to 2008 (Murray and Kaiser, 2012) there was little effect of defining the fishing year as running from June to May, rather than January to December. However, in recent years this definition has a greater relevance, particularly between 2009 and 2010. Fortunately, monthly landings are available from 2009 onwards. Where monthly landings were not available landings were allocated to each fishing year in proportion to time i.e. 7 months in year<sub>i</sub> (58%) and 5 months in year<sub>i+1</sub> (42%).



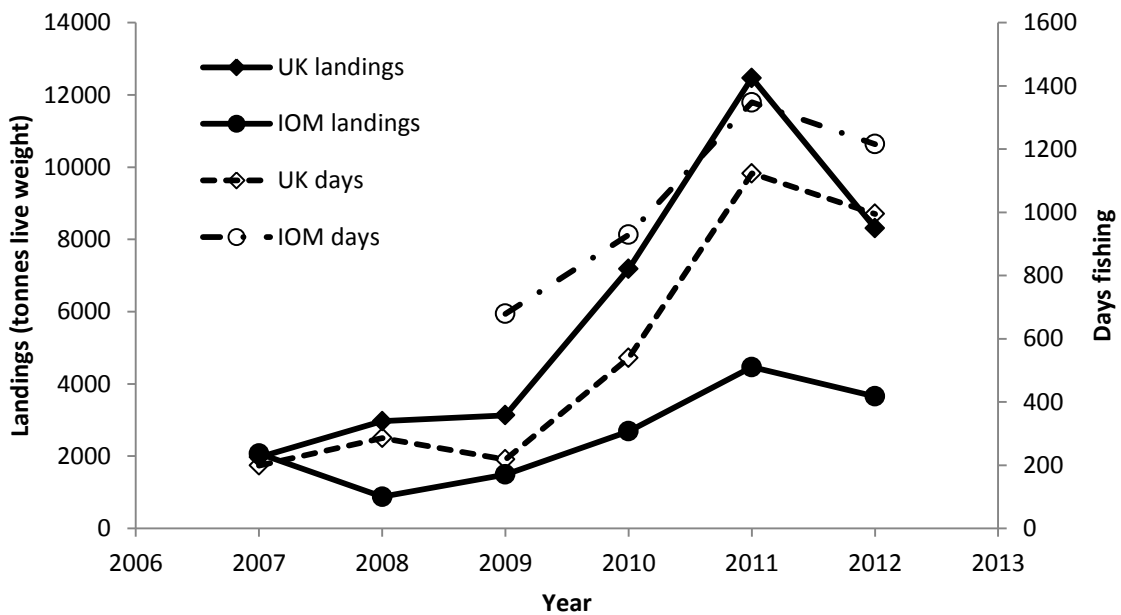
**Fig. 3. Landings (live weight) of queen scallops to the UK and Isle of Man. Landings are referenced to ICES statistical rectangles 36E5 and 37E5 (as a proxy for territorial sea landings) where possible. However, Isle of Man landings before 1994 are total landings to the Isle of Man, which are likely to be predominantly from these two statistical rectangles. Data source: Isle of Man Government, DEFA.**



**Fig. 4. Landings from 36E5 and 37E5 by UK and Isle of Man (IOM) dredgers (DRB), queen scallop trawlers (OTB) and *Nephrops* trawlers (TBN). Data are derived from the IFISH database and DEFA and are for calendar years (Jan. to Dec.) rather than fishing years.**



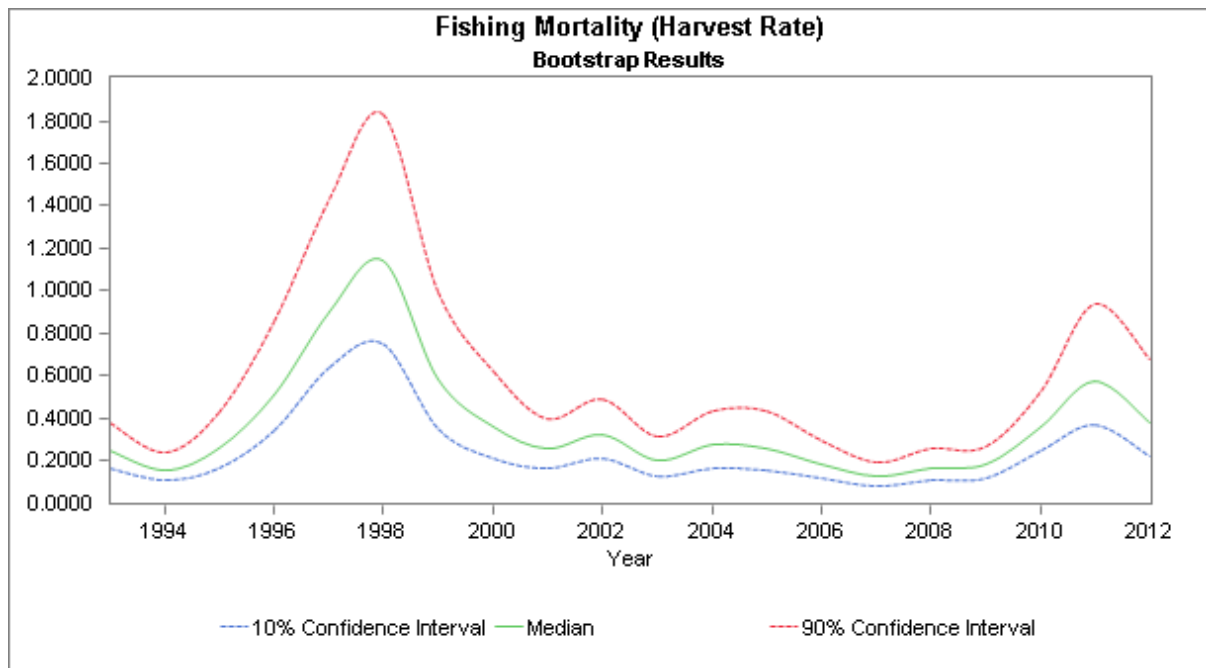
**Fig. 5. Estimated landings from the Isle of Man's territorial sea. VMS data were available only until the end of November 2011. These estimates are derived from VMS data combined with logbook data and include only data where matches were found between logbooks and VMS records. Data are for calendar years (Jan. to Dec.) rather than fishing years.**



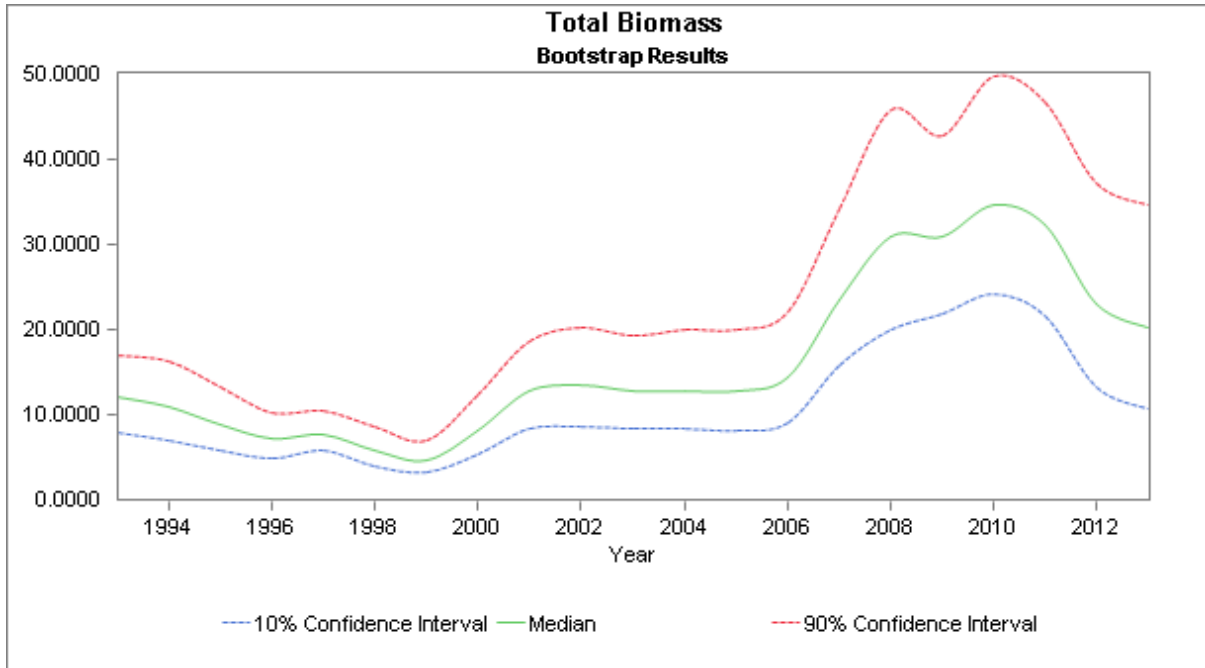
**Fig. 6. Landings from ICES statistical rectangles 36E5, 37E5 and 38E5 and days spent fishing for queen scallops by UK and IOM vessels. Days spent fishing by Isle of Man vessels are shown only from 2009 due to difficulty in accessing these data for earlier years.**

### 3.3 Stock assessment

The results of the Catch Survey Analysis showed consistent trends over time in fishing mortality and biomass estimates over a range of input data (Murray and Kaiser, 2012). However, the magnitude of the parameters did vary with changes in the allocation of recruits and post-recruits, natural mortality estimates and recruit selectivity. The greatest effect on the recruit and post-recruit indices resulted from changing the threshold size from 50 to 55mm (Murray and Kaiser, 2012). The stock assessment revealed sharp increases in fishing mortality in 2010 and 2011, with lower fishing mortality in 2012 (Fig. 7). Total biomass increased between 2006 and 2010 but has declined thereafter (Fig. 8). Biomass of both recruits and post-recruits decreased in 2010 and 2011 (Fig. 9). Biomass of recruits and post-recruits decreased slightly in 2012/2013, with a moderate increase in total biomass. Surplus production fluctuates widely between years (Fig. 10) and shows no relationship with biomass. Surplus production was around 5000t in 2011/2012 and 5700t in 2012/2013, following high values in 2006, 2007, 2009 and 2010 (Fig. 10). Following three years of increasing biomass (2005-2007), biomass has decreased during each of the past three years with the largest decrease occurring in 2011/2012 (Fig. 11) when landings were at their highest.



**Fig. 7. Fishing mortality estimated from harvest rate.**



**Fig. 8. Total biomass (1000s tonnes).**

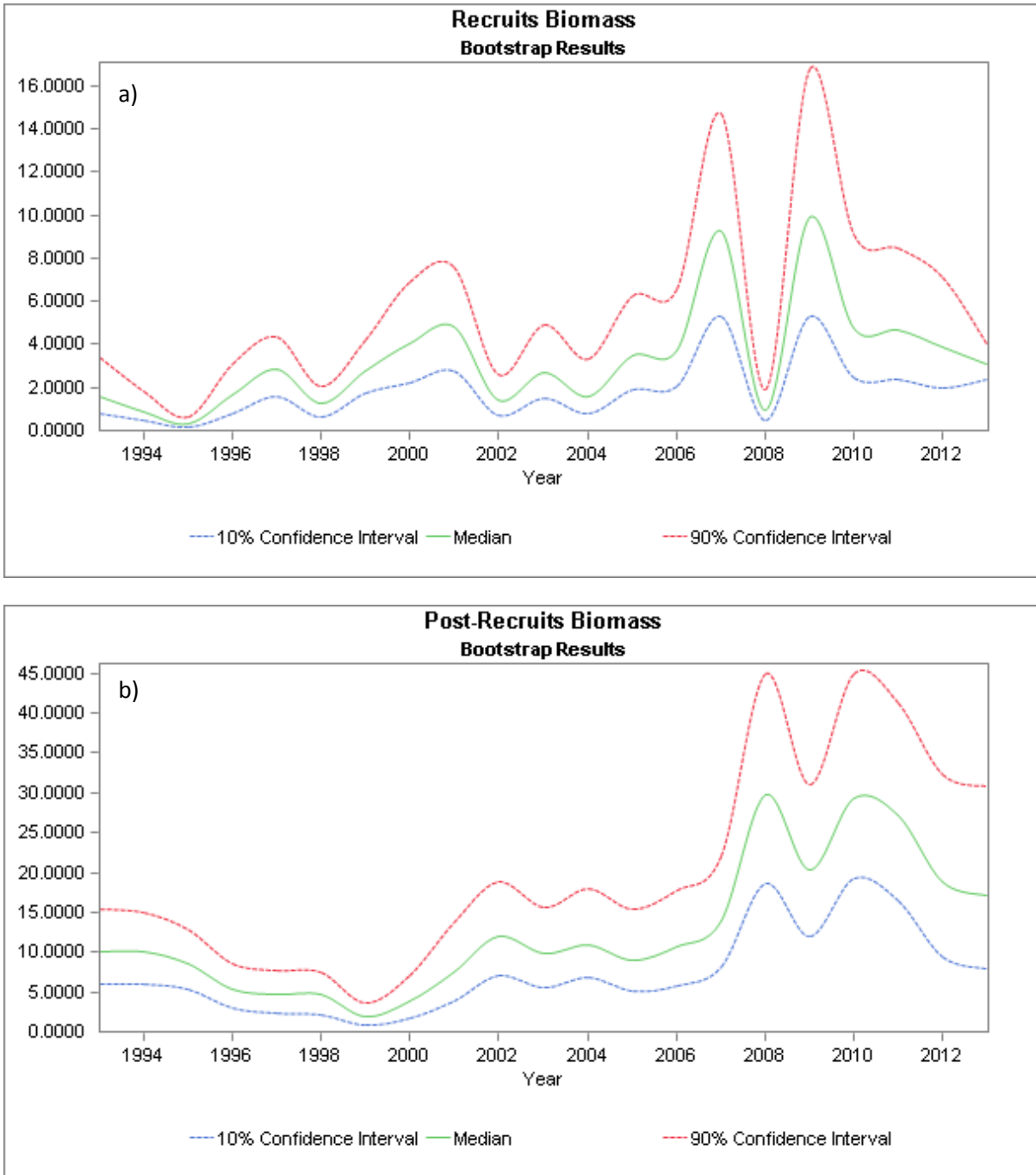


Fig. 9. Recruit biomass (a) and post-recruit biomass (b) (1000s tonnes).

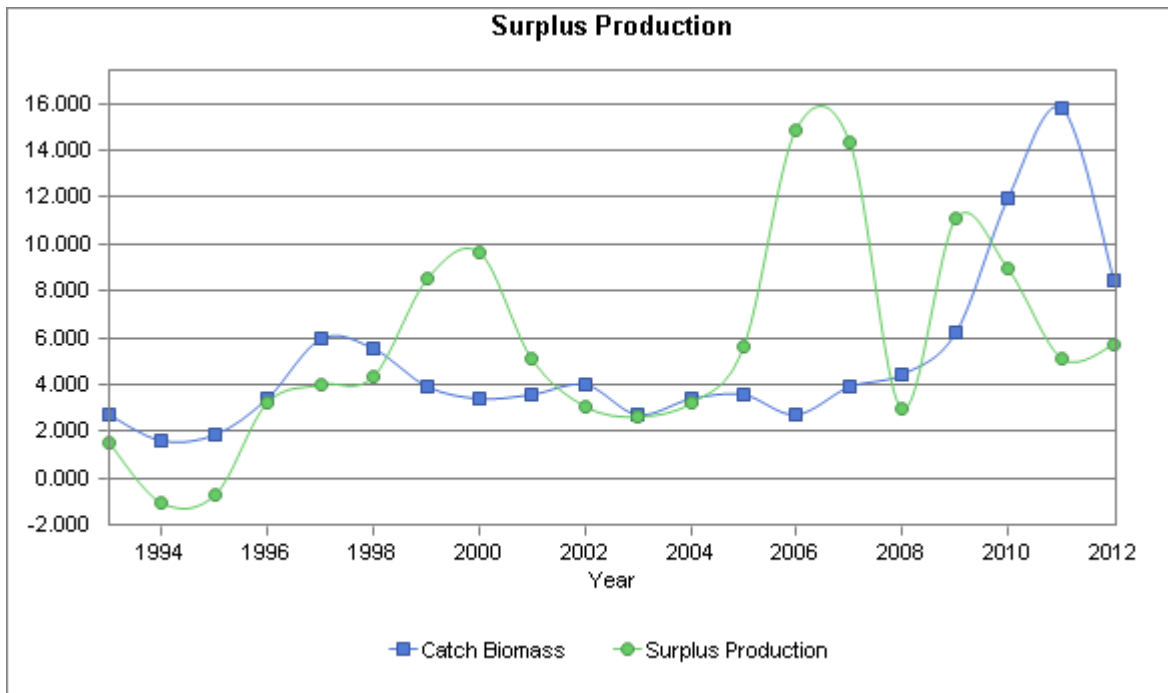


Fig. 10. Catch biomass and surplus production (1000s tonnes).

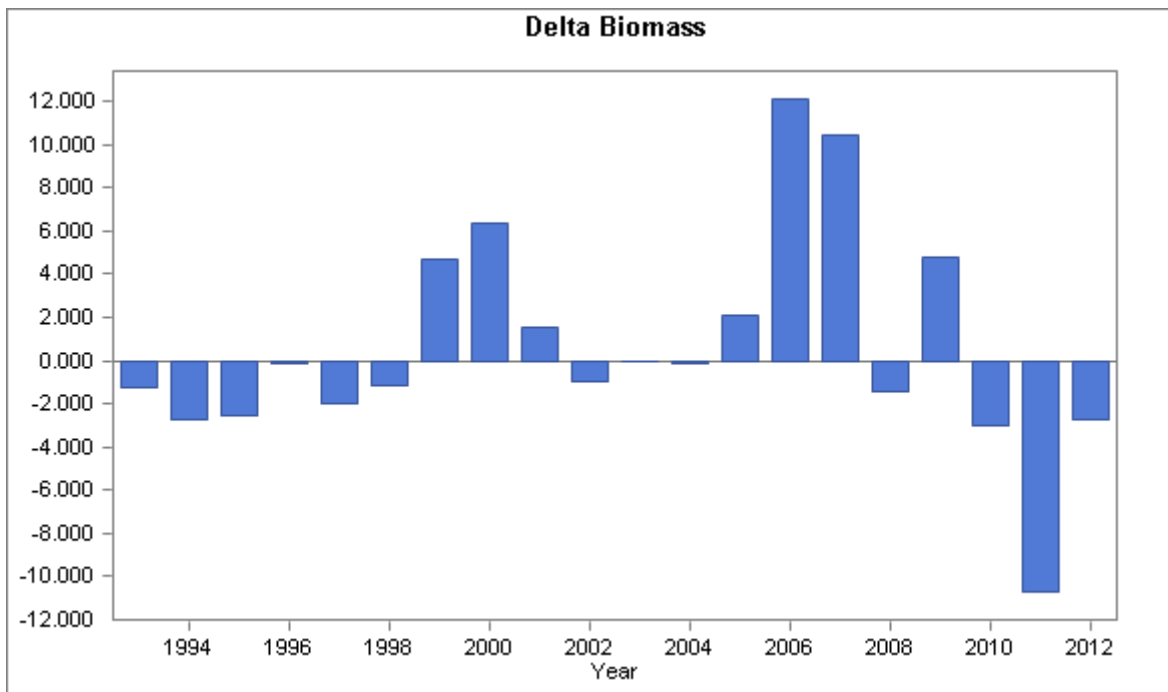


Fig. 11. Annual change in total biomass (1000s tonnes).



## 4. Discussion

### 4.1 Abundance indices

When scallop surveys commenced around the Isle of Man in 1992 queen scallop abundance was around seven times lower than in May 2011 and remained at this low level until 1999. Landings declined steadily between 1983 and 1992. However, relatively low exploitation levels during the past decade have allowed abundance to increase from the low levels observed in the past. The reason for the long period of low abundance is unclear but one possibility is that successful reproduction is dependent on the presence of queen scallops at a particular density as a result of Allee effects (Gascoigne *et al.*, 2009). Scallop egg fertilisation success is likely to be higher when adults are present at higher densities (Stokesbury and Himmelman, 1993; Claereboudt, 1999). Therefore, maintaining sufficient densities in at least some areas may be important to the fertilization, recruitment and long-term viability of the fishery.

The apparent increase in abundance of post-recruits between 2011 and 2012 needs to be interpreted with caution as this increase is driven largely by increases at Laxey and Ramsey, which are not major fishing grounds. Furthermore, landings from outside of the territorial sea will not be reflected in the survey indices over the short-term. Consequently, CSA model estimates show declines in biomass and abundance in contrast to the survey indices.

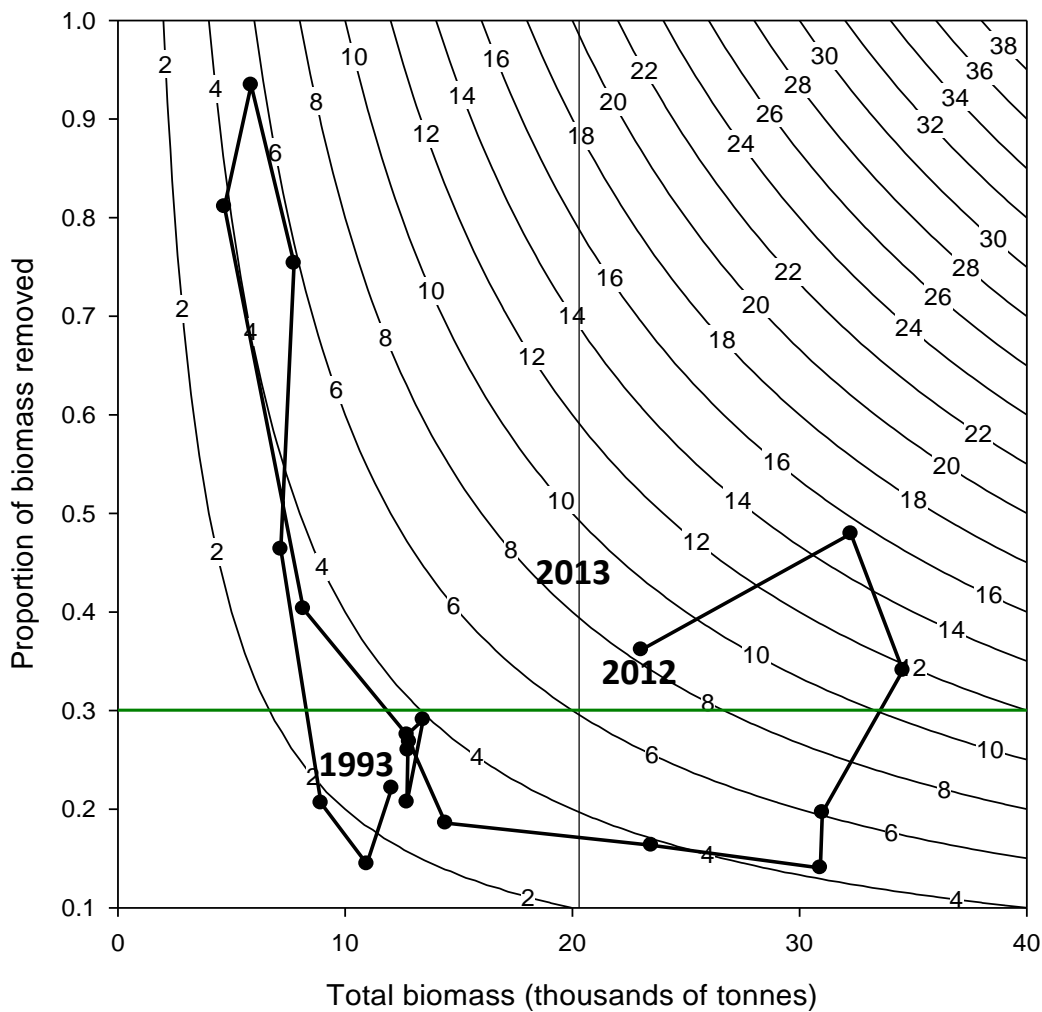
### 4.2 Impact on benthic habitats

In addition to the direct impact on the target species there are secondary effects that could lead to reduced larval settlement in the future. Trawling is generally considered to be less damaging to benthic habitats than dredging (Kaiser *et al.*, 2006). Consequently, the queen scallop dredge fishery failed to achieve MSC certification (Andrews *et al.*, 2010). Of particular relevance to the fishery is the fact that the habitats that support queen scallops may be damaged by excessive fishing activity. For example, there is a positive relationship between the presence of macroalgae and maerl and the abundance of juvenile scallops (Howarth *et al.*, 2011) and *Aequipecten opercularis* have been found to settle on bryozoans and hydrozoans (Lambert *et al.*, 2011). Within the territorial sea the greatest relative increase in effort is in the trawl fishery, while over the wider area dredging constitutes a much greater proportion of the area of seabed swept and landings. At fishing intensities prior to 2010 benthic conditions were clearly suitable for allowing large settlement of queen scallop larvae, as evidenced by the increase in abundance. Therefore, this level of fishing activity may provide an indicator of an appropriate, sustainable, level of fishing in relation to benthic habitats.

### 4.3 Stock assessment

The CSA model was robust to changes in parameters  $s$  and  $M$  in terms of the trends in biomass and fishing mortality. However, the absolute values of the model outputs were susceptible to different values of the input parameters. Increasing  $M$  resulted in much higher total biomass estimates (Murray and Kaiser, 2012). This would suggest that there has been a large standing stock since 2000. However, the dependence of the fishery upon scallops recruiting to the fishery in their second year of growth (Vause *et al.*, 2007) indicates that this is not the case unless  $M$  is unusually high for queen scallops over 2 years old. *Pecten maximus* have been found to become increasingly resistant to *Cancer pagurus* predation with increasing shell size, particularly once they reach 60 mm shell length

(Lake *et al.*, 1987); a similar relationship is likely to occur for *A. opercularis* and its predators. Discarded *A. opercularis* were also found to have high survival rates following fishing (Montgomery, 2008; Nall, 2011). Increasing  $s$  had a similar effect to increasing  $M$ , with higher biomass estimates, while decreasing  $s$  resulted in lower biomass estimates; these lower estimates lead to very high estimates of  $F$  (Murray and Kaiser, 2012).



**Fig. 12.** Landings in thousands of tonnes (contours) at different levels of total biomass and proportion of biomass removed. Solid points and connecting line indicate actual landings at modelled total biomass, and the proportion of biomass those landings are equal to, for each year from 1993 to 2013. Green line indicates recommended maximum proportion of biomass removed. Solid vertical line shows estimated mean biomass in February 2013.

With total biomass of 13000t and around 25% of biomass removed annually the fishery has experienced both increases and decreases in total biomass, reflecting the fishery's dependence on annual recruitment (Fig. 12). The largest increases in biomass occurred where biomass was >13000t. Therefore, 13000t is recommended as a critical minimum biomass. Furthermore, there is no evidence that the population reached carrying capacity at biomass of 30000t, so there is a strong case for maintaining biomass at a higher level. In terms of setting an appropriate harvest rate it is clear that removing more than 30% of queen scallop biomass increases the risk that the stock will be depleted. By comparison, in the Patagonian scallop fishery the TAC is set at 40% of biomass (Morsan *et al.*, 2012). In the Isle of Man queen scallop fishery, where 40% or more of biomass has been removed there has been no major annual increase in biomass. The median estimated biomass in 2013 is 20000t. Removing 30% of biomass would equate to around 6000t. This is slightly higher than average surplus production since 1993, which was estimated at 5600t, so limiting landings to lower than this level would reduce the risk of depleting biomass. It is important to note that the inclusion of additional survey stations in 2012 and 2013 resulted in slightly higher biomass estimates than in previous years, particularly in 2012. However, landings in 2012 still exceeded surplus production, leading to a further decline biomass in 2012. Given the depletion of biomass and the risk that biomass is reduced to less than 13000t it is recommended that no more than 5000t (25% of biomass) is removed from 36E5 and 37E5 in the 2013/2014 fishing season. To facilitate management of the fishery allocating a proportion of these landings to the territorial sea may be beneficial. In recent years around 50% of landings have been taken within the territorial sea.

These thresholds are subjective but can be used by fisheries managers as a guide in implementing management measures for the fishery. Furthermore, the combination of low total biomass and the removal of a high proportion of biomass must be interpreted as a high risk strategy for the fishery and will sustain only low annual landings. Biomass was still relatively high in May 2011 but high landings in the years since have depleted biomass. The possibility of under-fishing must also be considered. This could lead to the population reaching carrying capacity, reduced growth rates, a high proportion of senescent scallops in the population, and higher natural mortality rates. However, given the recent depletion of biomass and high level of landings this is not of immediate concern. Furthermore, the current fleet has the capacity to increase fishing effort very quickly as evidenced by the increase in fishing effort between 2009 and 2011. Despite its dependence on scallops recruiting in their second year of growth, the fishery has been resilient to collapse.

It is important to note the increase in biomass in the fishery occurred following a period of three years when landings exceeded surplus production and was followed by several years of strong recruitment. Therefore, there are clearly variables other than fishing effort that will influence the success of the fishery; these include environmental parameters, particularly temperature, and fishing activity outside of the stock assessment unit. We have not attempted to identify reasons for this period of strong recruitment in this report, although this will form the basis of future work.

There are several areas where further work can help to verify or improve data quality. Aspects that can be refined with additional work include gear selectivity and recruit abundance. The abundance index could also be improved by including additional sampling stations outside of the territorial sea to ensure the index is truly representative of the stock size. This may become particularly important given the changes in management within the territorial sea, including the closure of the fishery in 2012. Nevertheless, the proportion of scallops caught within the territorial sea has remained

consistent over the past three years. Further work to establish the appropriate stock assessment unit is a priority. Queen scallops within the Irish Sea are generally thought to consist of a single stock (Beaumont, 1982; Macleod *et al.*, 1985). Therefore, ideally, the Irish Sea fishery would be managed as a single stock with management advice provided based on data collected across the Irish Sea.

#### 4.4 Wider-scale issues

Recruitment of queen scallops can be highly variable. As well as numerous environmental variables that may affect the reproductive success and mortality of queen scallops there have been many changes in the fishery itself. The fishing gear used to target queen scallops has changed over time and dredgers and trawlers are potentially targeting different sizes of scallops. The impact of the various fishing gears on benthic habitats is different and catchability of queen scallops varies between gears (Hinz *et al.*, 2009). Catchability of queen scallops is also temperature dependent (Jenkins *et al.*, 2003). Management of the fishery has changed substantially during the past two years. The introduction of closed areas, increasing minimum landing size (to 50 mm) and a closed season will all impact on the queen scallop population. The accuracy of historical landings data is unknown but is almost certainly subject to large errors. Therefore, a great deal more research over many years is needed. Nevertheless, there is sufficient information to allow the fishery to be managed to sustain or increase yields.

## 5. Conclusions

- Fishing mortality was lower in 2012/2013 than in the previous two years.
- Depletion of total biomass will render the fishery heavily dependent on annual recruitment.
- It is recommended that the **maximum** percentage of biomass removed from the fishery is 30%, and that biomass of the stock is maintained at >13000t (preferably higher).
- For the 2013/2014 fishing year a precautionary limit on landings from ICES statistical rectangles 36E5 and 37E5 would be approximately 5000t, which equates to 25% of biomass.
- Alternative management measures, such as closed areas, will help to limit the environmental impact of the current high levels of fishing effort.
- Further work is required to understand the relationships between environmental variables and the reproductive success of queen scallops.
- CSA is generally well-suited to the data available from the queen scallop fishery. Improving, or verifying, the quality of input data will be the focus of ongoing research.
- Further work is needed to define the most appropriate stock assessment unit. Mismatch between the management unit (territorial sea) and the unit over which landings are recorded (ICES statistical rectangles) limits the precision of biomass estimates.

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