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The Isle of Man *Aequipecten opercularis* fishery stock assessment 2015

Final Report

May 2015

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To cite this report: Bloor, I.S.M., Murray, L.G., Dignan, S.P. and Kaiser, M.J. (2015). The Isle of Man *Aequipecten opercularis* stock assessment 2015. Fisheries and Conservation Report, Bangor University. pp. 30.

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. Following a decline in stock status in 2014 and an estimated mean biomass below the recommended minimum threshold of 13000t, under which recruitment is considered to be impaired, the MSC certification for this fishery was suspended on May 19th 2014.

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 between 2010 and 2013; however, following a decline in stock status landings declined in 2014. Across ICES rectangles 36E5 and 37E5, in 2014, approximately 82% of landings were taken by dredgers and 18% by otter trawlers (Jan. to Dec.). By comparison, within the territorial sea otter trawlers caught 100% of total landings (Jan. to Dec.).

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 both recruits and post-recruits declined between 2010 and 2013, while post-recruits continued to decline between 2014 and 2015, biomass of recruits increased slightly in 2014 and declined again in 2015. Total biomass was estimated to have declined by over 45481t between 2010 and 2015. Landings in 2014 were lower than in 2013, at 6848t (Jan. to Dec.).

Biomass is very likely to be depleted leading to the fishery becoming recruitment-dependent where >40% of biomass is removed annually. To minimise the risk of queen scallop biomass depletion it has been recommended that no more than 30% of biomass is removed in any year. In addition, biomass of the stock within the stock assessment unit should be maintained at ≥ 13000t (preferably higher). Given recent biomass depletion, a TAC could not be advised for the 2014/2015 season for ICES Rectangles 36E5 and 37E5. However, an actual TAC of 1000t was set by the Queenie Management Board for the territorial sea. Recorded landings for 2014 (from 36E5 and 37E5) indicated that around 87% of total estimated biomass was removed from the stock assessment unit (1st June to 31st May). This has led to substantial depletion of the stock biomass.

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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. For the 2014 fishing season these included:

- Four temporary closed areas where fishing for queen scallops by any means was prohibited.
- Queenie conservation zones where dredging for queen scallops was prohibited.
- Spawning protection closure (1st April to 31st May)
- Weekend ban
- Daily curfew (06:00 – 18:00)
- Daily bag limits (maximum of 1650 kg per vessel per day)
- Minimum landing size (55 mm)
- Limited days (4 days a week)
- Limited TAC (1000 t)

These management measures were covered by the Fisheries Act 2012, the Isle of Man Sea-Fisheries (queen scallop fishing) bye-laws 2013 (Statutory document No. 0160/2013) and through restrictive licencing conditions.

Outside of the territorial sea although a minimum landings size of 40 mm is enforced the fishery has no closed seasons and 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. As of 19th May 2014 the MSC certification for the Isle of Man's queen scallop trawl fishery was suspended following a decline in stock status, with an estimated mean biomass for 2014 at levels below the threshold at which recruitment is considered to be impaired.

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 29th 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 21st July 2011, identified an increase in demand for queen scallops combined with increased catching capacity. In July 2013 a meeting of the Scallop Association was convened to discuss the lack of management in Irish Sea queen scallop stocks and requested action by the UK and Isle of Man fisheries administrations, specifically that the UK increase minimum landing size to 50mm and that closed seasons between January-February and June-July were introduced.

In August 2014, and partly in response to the decreased stock assessment for Manx waters, the Isle of Man Government's Department of Environment, Food and Agriculture (DEFA) began working with the relevant UK administrations to develop a Pan-Irish Sea Management strategy for queen scallops. The first discussions of this group were held on the 18th August 2014, and monthly communications, including a formal meeting on the Isle of Man, have continued into 2015. In March 2015 the first meeting with the scallop fishing industry was held in Edinburgh, and a joint Industry and Fisheries Administrations Working Group was established to determine which management measures should be adopted and how this could be achieved. Changes to minimum landing size and seasonal closures remain the primary short-term options with entry restriction considered as a potential long-term objective. This process continues, with the first meeting of the Working Group scheduled for 20th May 2015.

1.4 Stock assessment

An annual stock assessment of the Isle of Man queen scallop stock has been undertaken using the Catch-Survey Analysis (CSA) method, first developed by Collie and Sissenwine (1983), since 2012. The results of which are presented by Murray and Kaiser (2012, 2012b), Murray (2013) and Bloor *et al.,* (2014). 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 2014, the estimated mean biomass declined to well below the 13000t precautionary threshold; as such it was not possible to recommend a scientifically advised TAC for the 2014/2015 queen scallop fishery. In order to reduce the risk of biomass being further depleted and, preferably, to promote successful recruitment and an increase in biomass, it was recommended that no fishing occurred within the stock assessment unit (ICES rectangles 36E5 and 37E5) (Bloor *et al.,* 2014).

1.5 Scientific steering committee

Following feedback from industry after the results of the 2014 stock assessment survey were presented, a scientific steering committee was set up by DEFA in 2014 which encompassed a representative selection of members of the Manx fishing industry. A scallop subgroup of this committee met in February 2015 to discuss the survey methods for the annual stock assessment.

The outcomes of this meeting, in terms of queen scallops, included recommendations to:

- Incorporate into the stock assessment survey sites outside of the 12nm selected using local industry knowledge by members of the scientific steering committee subgroup.
- Extend the coverage of the current survey to include additional survey stations within the 12nm which local industry felt represented important fishing ground not covered by the current stations.
- Undertake a gear comparison trial with a local fishing vessel at a selection of sites within the stock assessment survey to enable industry to undertake additional, comparable sampling in the future.

These recommendations were all addressed by Bangor University during the April 2015 stock assessment survey.

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) at a range of 11 historical survey stations, most survey stations have only been visited intermittently, although latterly with increased sampling effort (Figure 2 and Appendix 1). In 2014 the autumn survey ceased and effort was concentrated in a single annual survey, to take place in April each year. The abbreviations for these historical survey station names 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), Peel (PEL), Point of Ayre (POA) and Targets (TAR) (Figure 2). In 2012, 2013, 2014 and 2015 sampling effort was increased to include stations across the extent of the queen scallop stock within the territorial sea (Figure 1 and Figure 2). In 2015, following advice from the scallop subgroup of the scientific steering committee, additional stations were surveyed outside of the Isle of Man's territorial sea (Figure 2).

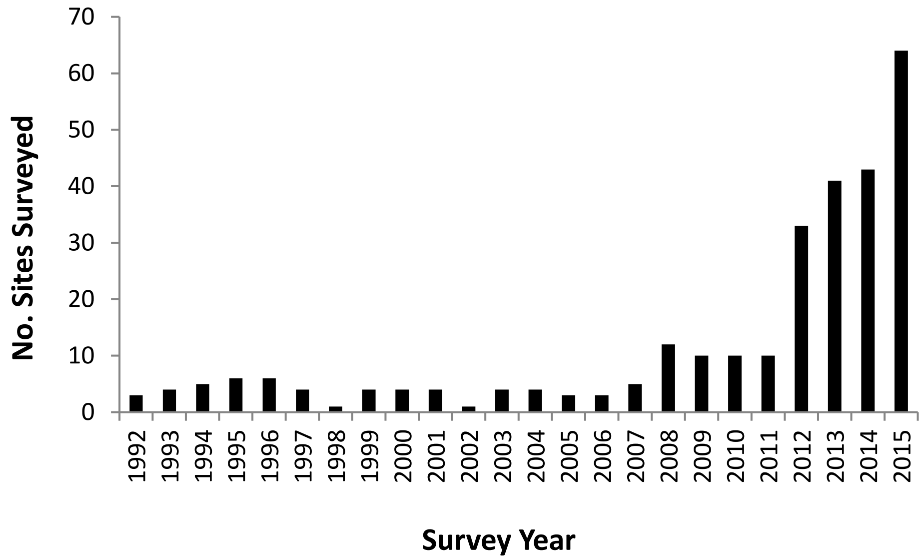

Figure 1: Sampling frequency for survey stations within the annual spring scallop stock abundance surveys indicating the substantial increase in survey sampling effort from 2012 onwards.

Stations that have been sampled over at least two years (3, 4, 5, 6, 8, 9, 14, 16, 17, 18, 20, 21, 22, 23, 24, 25, 29, 30, 32, 33, 34, 35, 38 and 39), in addition to the standard historical queen scallop survey stations (BRI, CHI, EDG, LAX, PSM, RAM, SED and TAR), were included in the stock assessment (Figure 3). Stations in ICES statistical rectangle 38E5 (and landings from this area) were not included in the main stock assessment since this area was not surveyed before 2008 and only a single station has been sampled in most years since then; although at least three stations (POA, 10, 45) have been sampled in 2014 and 2015 (Appendix 1). However, separate stock assessment models were run which incorporated stations (and landings) from ICES statistical rectangle 38E5, in order to provide an estimate of the biomass for all three ICES rectangles (Appendix 3 and 4). All stations were surveyed using the protocol described by Hinz *et al*. (2009) and Murray *et al*. (2009). This year the RV Prince Madog conducted the stock assessment surveys in April 2015.

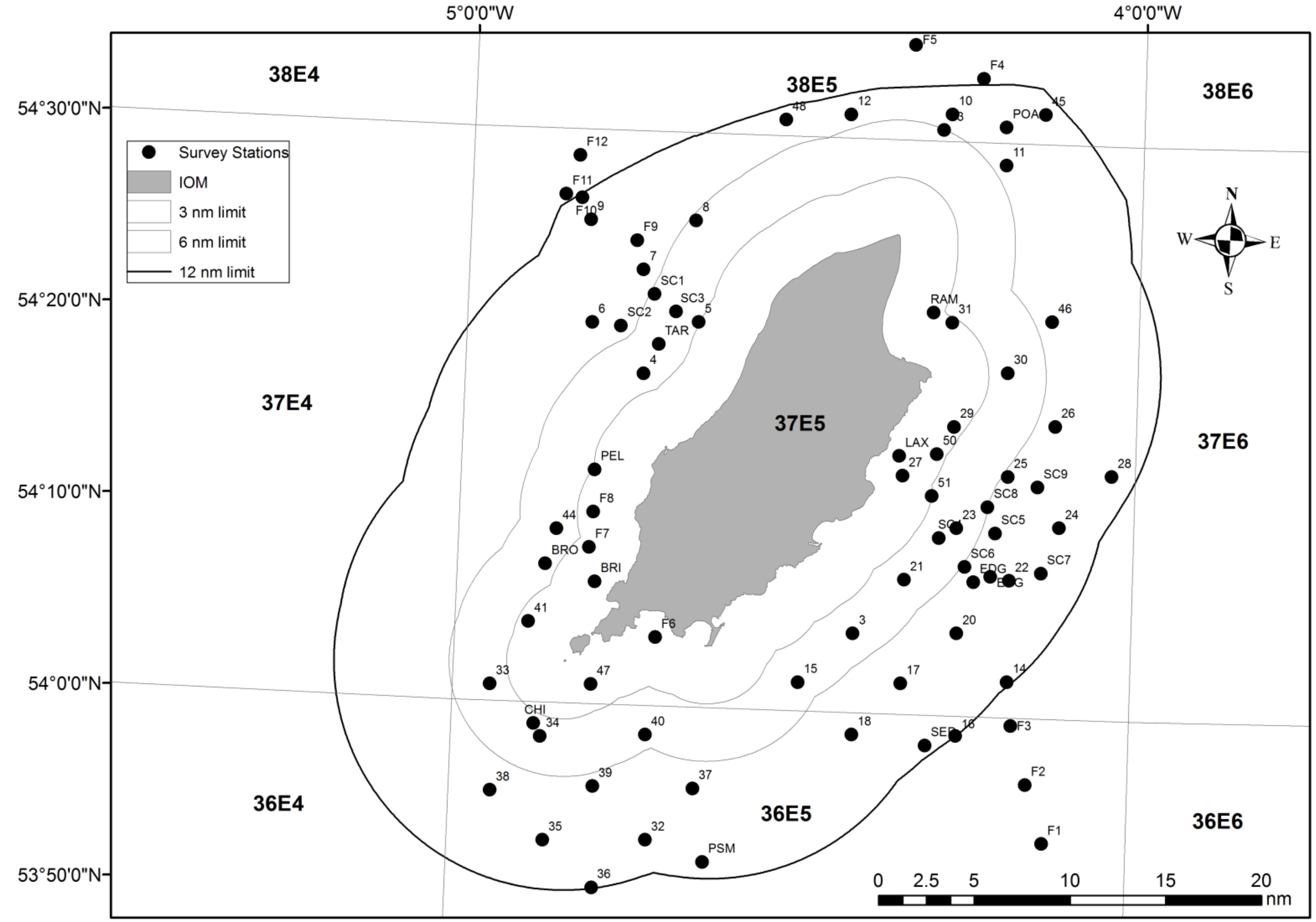

Figure 2: Map showing all stations surveyed during the 2015 stock abundance survey and in previous annual stock abundance surveys. Stations prefixed with an 'F' are stations selected by local fishing industry representatives, stations prefixed with 'SC' were scientific stations added to provide higher intensity monitoring of the density of queen scallops within closed areas. Named stations were first surveyed from 1992 whilst numbered stations were first surveyed from 2012.

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.

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 $P = 1/(1 + e\text{-}r^{(L-Lc)})$ allowing the proportion retained, P, in each size class to be estimated.

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. Boyle (2012) showed considerable predation by dabs (*Limanda limanda*) on discarded queen scallops, this could be the result of an increase in stress and a decrease in escape response, causing the scallops to gape and be eaten by fish in this way. 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 5% of the weight landed. However, *in situ* mortality resulting from interaction with fishing gear is unknown.

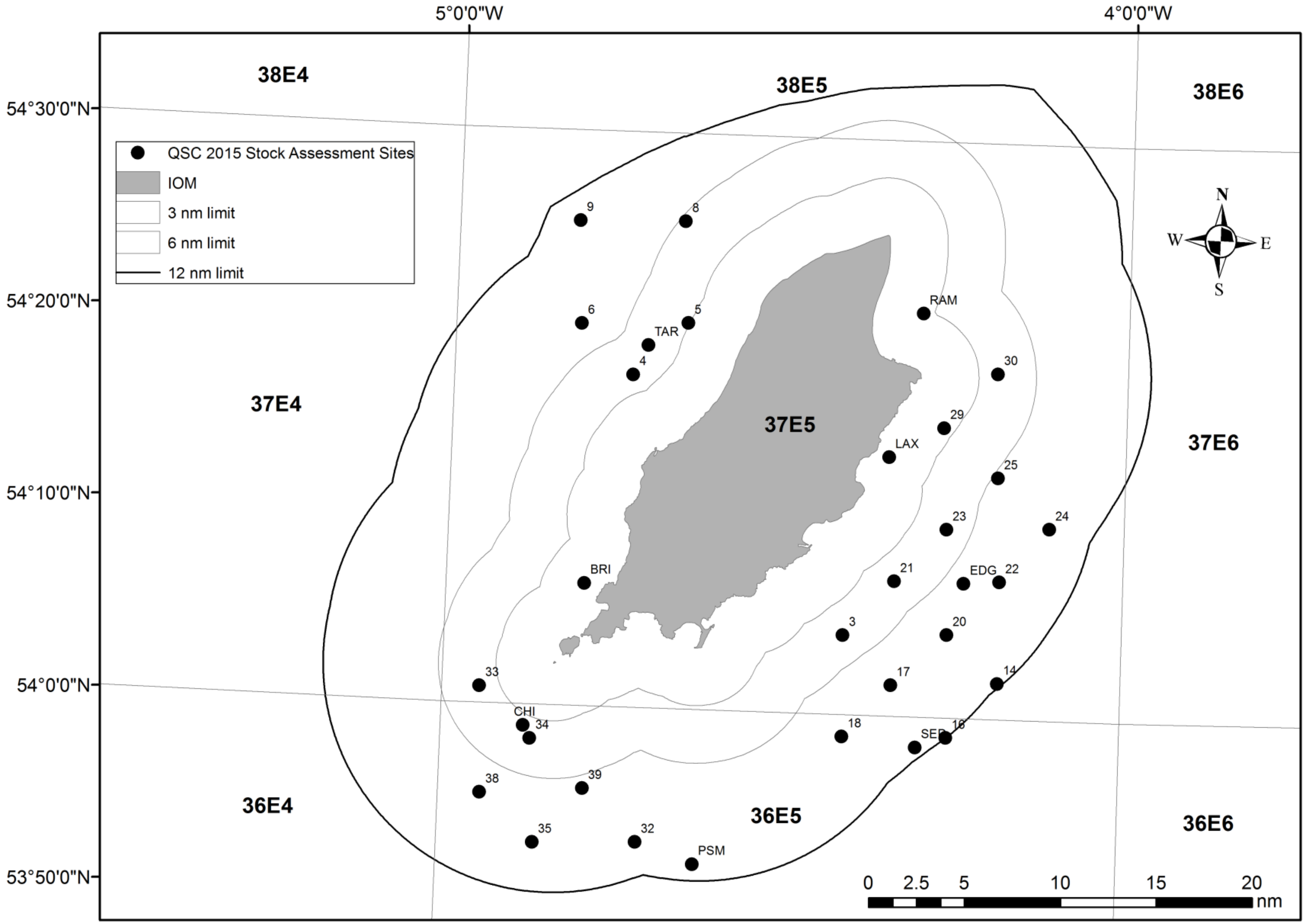

Figure 3: A map displaying only the actual survey stations within the Isle of Man territorial sea used in the 2015 queen scallop stock assessment model. Named stations were first sampled from 1992 onwards, whilst numbered stations were first sampled from 2012 onwards. For 2015, the stock assessment presented in the main section of this report was undertaken for the area of the two ICES rectangles 36E5 and 37E5.

2.2 Stock assessment

The stock assessment was implemented using CSA v3.1.1 (NOAA, 2008) [for comparison a stock assessment using the latest model version (CSA v4.3; NOAA, 2014) can be found in Appendix 2]. 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 defined as the area covered by ICES statistical rectangles 36E5 and 37E5 (Figure 3), which includes the majority of queen scallop fishing grounds within the territorial sea. 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 were available to us for these ICES statistical rectangles only. A third ICES rectangle (38E5) also covers one of the main fishing grounds within the territorial sea and models that include landings and stations from within this area can be found in Appendix 3 and Appendix 4.

Abundance indices were derived from survey data from 1993 to 2015. Data from 1992 was not included in the assessment since only three stations were surveyed in this year, one of which was surveyed only until 1997 (Appendix 1). The geometric mean across survey stations selected for the model 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; *τ* 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 ≥55 mm length; thus, catches were assumed to consist of scallops ≥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 85 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_∞ = 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) and repeated in Appendix 10. Based on the earlier work of Murray and Kaiser (2012) 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:

$$h = \frac{C_t e^{\tau M}}{R_t + N_t} \qquad (5)$$

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, 2005a). The harvest rate is calculated based on population estimates in numbers. In CSA version 3.1.1 the 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.

2.3 Closed areas

In May 2014 the QMB met to discuss the scientific advice based on the biology and sustainability of the stock that recommended no fishing (Bloor *et al.,* 2014). Considering the socio-economic impacts of such a closure a limited economic TAC of 1000t for the territorial sea was recommended by the Board and subsequently enacted by the Minister for DEFA. Fishing was conditional on the fact that strict monitoring and enforcement of the TAC was undertaken and additional conservation measures put in place to try and limit the negative impacts of fishing on an already depleted stock. These measures included the introduction of small, temporary closed areas within which fishing for queen scallops would be prohibited.

Queen scallops are simultaneous hermaphrodites (i.e. an individual has both male and female reproductive organs) and become sexually mature at 1-2 years (approximately 40mm). Queen scallops are broadcast spawners (i.e. they release eggs and sperms into the sea) and can spawn in both spring and summer (Duggan, 1987). When one individual spawns, pheromones contained in the eggs and sperms which are released into the water column, signal to neighbouring scallops to release their own eggs and sperms ensuring synchronous spawning (AFBI, 2012). Thus, in order for spawning (and subsequently recruitment) to successfully occur queen scallops need to be present at relatively high densities. In low density populations there is a risk that the spawning stock may not be present at high enough densities to successfully reproduce (i.e. there are too few individuals around to come into contact for fertilisation), a phenomenon known as the Allee effect (AFBI, 2012).

The decline in stock status evident in 2014 meant that large areas of the territorial sea contained low densities of queen scallops. For the 2014/2015 fishing season four areas that had exhibited sufficiently high abundances in the April 2014 stock survey were strategically closed around the Island. These areas were intended to ensure that some high densities of queen scallops remained during both the spring and autumn spawning periods to promote successful spawning. Given the simulations of scallop larval connectivity that have been produced for the Isle of Man's territorial sea (Neill & Kaiser, 2008), a single area was closed within each of the four main fishing grounds to try and ensure the best chance of recruitment around the entire Island (Figure 4).

As the main purpose of the closed areas was to promote successful spawning and spat delivery to areas around the entire Island, the effects of these closures will need to be monitored over several years to assess whether any positive impact on recruitment has occurred. Monitoring of these closed areas, including dredge and camera tows at additional survey stations (Stations labelled 'SC'; Figure 2), was therefore initiated during the 2015 stock abundance survey.

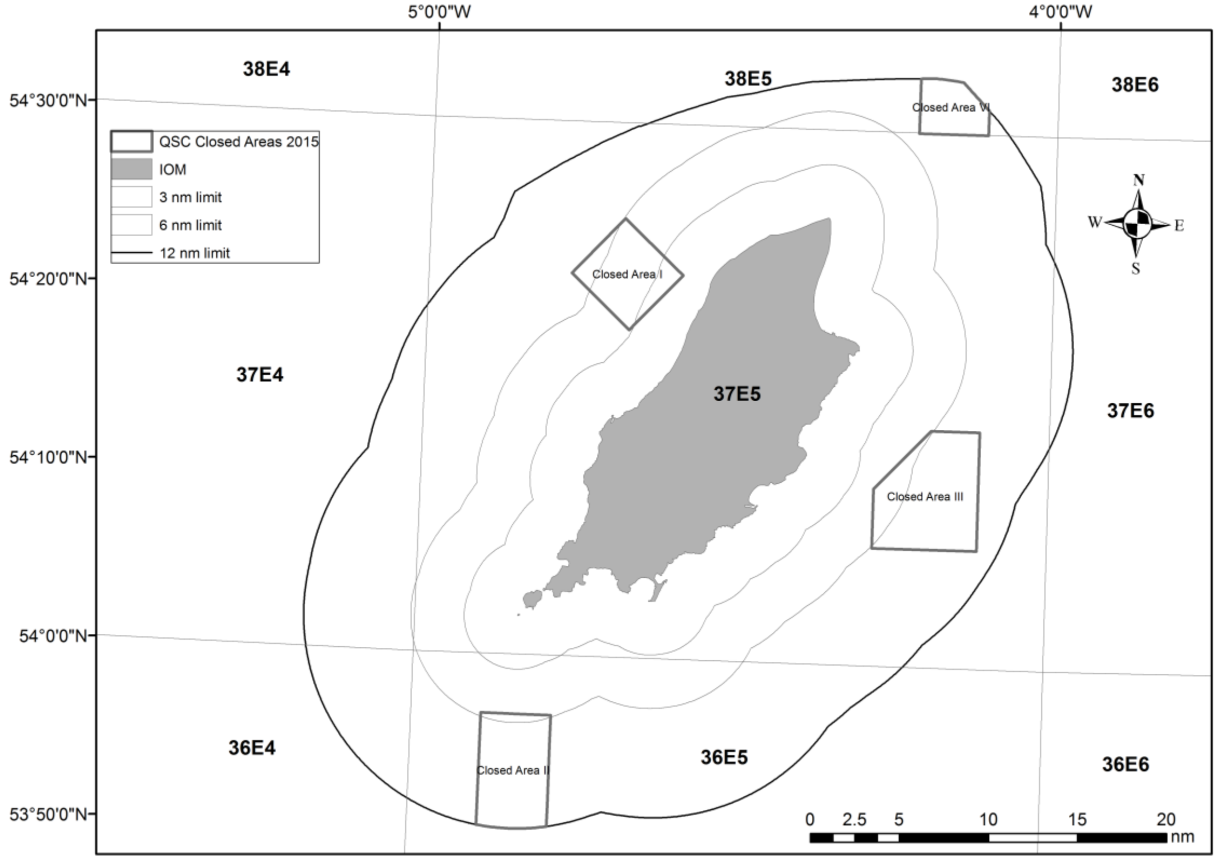

Figure 4: Four temporary queen scallop closed areas that were put in place for the 2014/2015 fishing season. Of these closed areas, Closed Area II, III & IV remained in place for the duration of the 2014/2015 king scallop fishing season as well.

3. Results

3.1 Abundance

3.1.1 Whole Stock

Mean abundance of recruits has declined each year from 2009 to 2013, there was a slight increase in 2014 with a decrease observed again in 2015 (Figure 5). From 2006 to 2010 there were year on year increases in the mean abundance of post-recruits, with abundance reaching the highest levels on record in 2010. However, the mean abundance of post-recruits declined sharply between 2012 and 2015 (Figure 5).

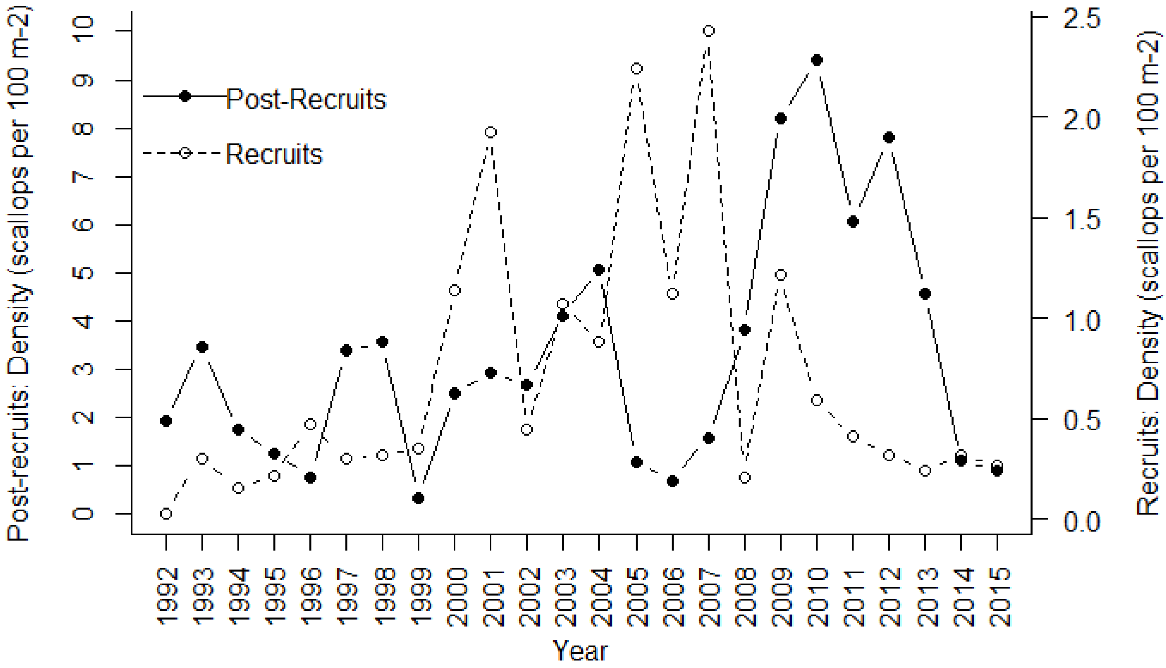

Figure 5: Abundance indices (based on geometric mean) for recruits and post-recruits used in the catch survey analysis model. This is calculated using data from only the stations used in the 2015 stock assessment model. Zero data values have been treated as 0.01 in order to calculate the geometric mean.

3.1.2 Territorial Sea

Whilst the biomass of the whole stock has declined annually since 2011, densities vary significantly among the four main fishing grounds: East Douglas (EDG), Chickens (CHI), Targets (TAR) and Point of Ayre (POA) (Figure 6). In addition, due to the aggregating nature of queen scallops some areas of relatively high densities are evident within each of these fishing grounds.

The average density of queen scallops (of all sizes caught) per 100 m^2 among historical survey stations around the Isle of Man can be seen in Figure 7. The historical stations to the north and west of the Island (TAR and POA) have the highest densities of queen scallops per 100 m^2 whilst sites to the east of the Island (SED, EDG & LAX) have the lowest densities (Figure 6 and Figure 7).

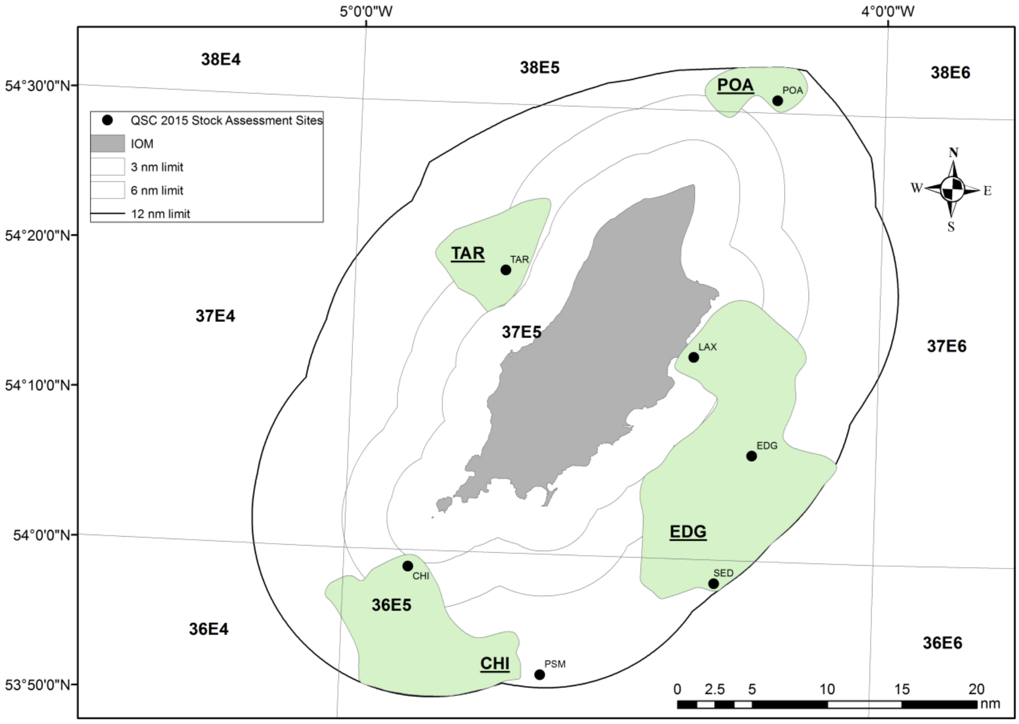

Figure 6: Map showing the approximate locations of the four main queen scallop fishing grounds (names underlined and in bold for clarity) within the territorial sea. The four main fishing grounds are known as EDG (East Douglas), CHI (Chickens), TAR (Targets) and POA (Point of Ayre). The historical stations within these sites are also labelled on the map.

Variation in the average density of queen scallops (of all sizes caught) per 100 m^2 also varies temporally as can be seen in Figure 8 where the survey densities from 2009 and 2015 are compared. This graph indicates a large decrease in scallop density since 2009, when there was a large recruitment event at historical stations on the south and east of the Island.

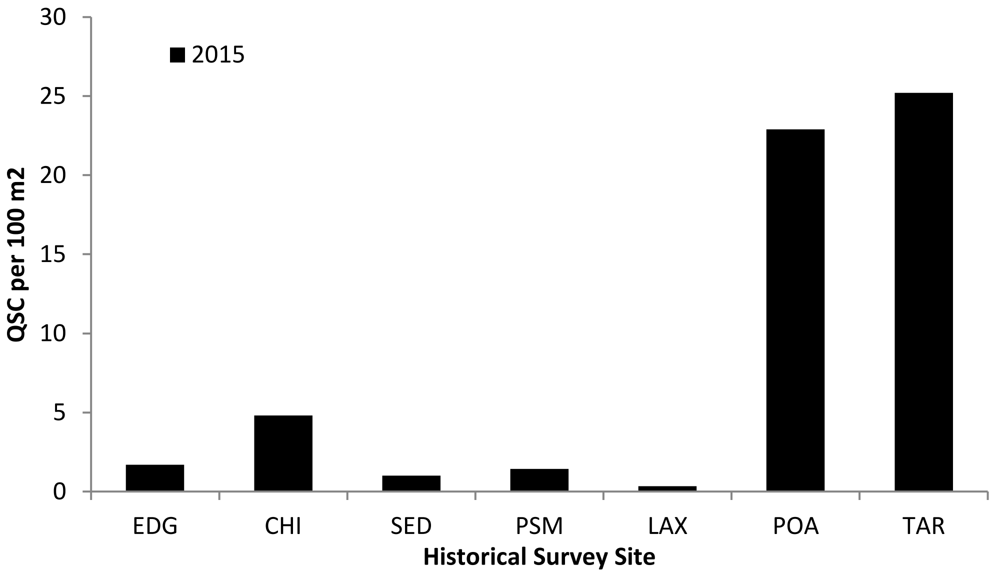

Figure 7: Average density of queen scallops (number of scallops per 100 m^2) in queen scallop dredges from historical survey stations during the 2015 stock assessment survey

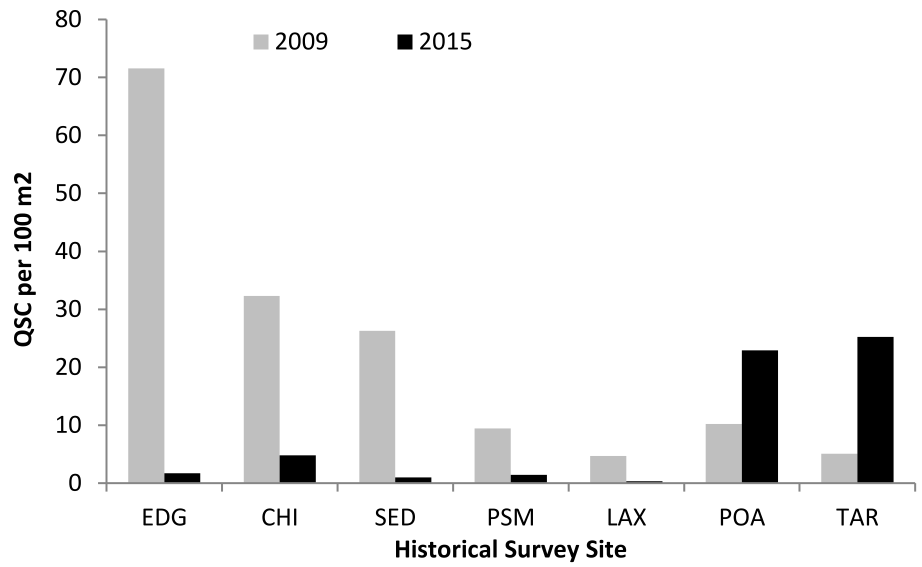

Figure 8: A comparison of average density of queen scallops (number of scallops per 100m^2) in queen scallop dredges from historical survey stations during the 2009 (grey) and 2015 (black) stock assessment survey.

In addition, the proportion of recruits and post-recruits at each station also varies around the Island. Whilst some sites (e.g. SED) were composed entirely of post-recruits (over 55 mm) other stations (e.g TAR) were composed of equal proportions of recruits (25 – 54 mm) and post-recruits (over 55 mm) (Figure 9). In addition to the historical station at SED, Stations 5, 7, 31 and 36 - which are all located within closed areas around the Island (Figure 6 and Figure 2) - were also composed entirely of post-recruits. In addition to the historical station at TAR, Stations 35, 38, 32, 34 and 33 -all located within the fishing ground at Chickens in the south of the Island (Figure 6) - were composed of over 50% recruits.

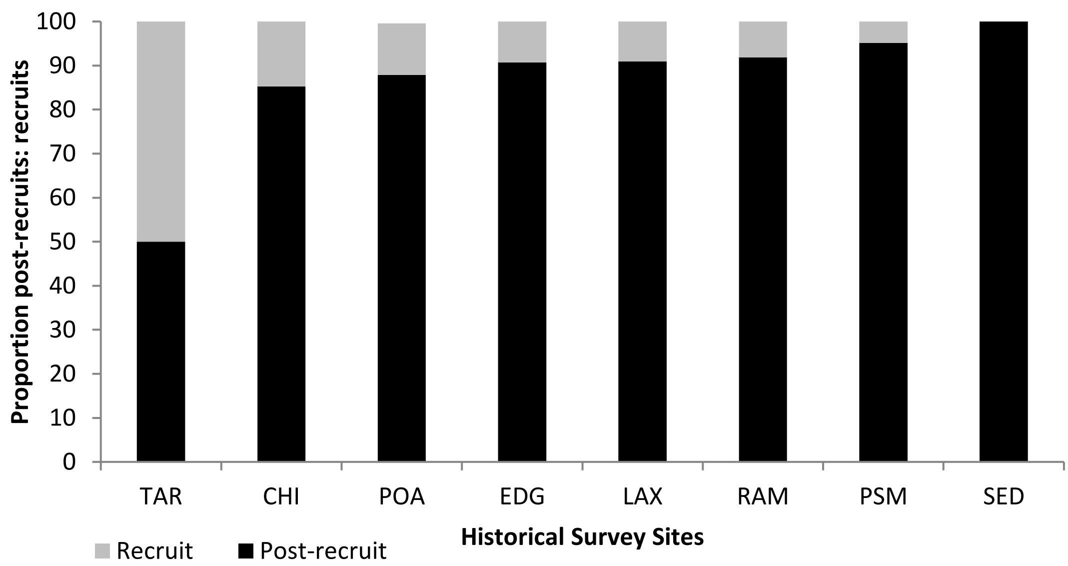

Figure 9: Proportion of recruits to post-recruits in the queen scallop dredges for historical stations in 2015

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.

Queen scallop landings from 36E5 and 37E5 totalled 6848t in 2014 (Jan. to Dec.), with an additional 256t caught in 38E5 (Jan. to Dec.). This was a substantial decrease from the 12301t landed in 2013 (Jan. to Dec.) (Figure 10). This decline in landings occurred across all gear types, for both UK and IOM vessels (Figure 11). Of the total taken across the two rectangles (36E5 and 37E5), 5608t was caught by dredgers, 1240t by otter trawlers, and 0t by *Nephrops* trawls. Landings taken from 36E5 and 37E5 by Manx trawlers represented 14% and UK trawlers represented 4% of total landings in 2014. UK dredgers represented 80% and Manx dredgers represented 2% of total landings in 2014. Landings of queen scallops from within the territorial sea were approximately 1000t in 2014 (Figure 12); this represents only 15% of total landings from 36E5 and 37E5 (Jan. to Dec.). The origin of landings within the territorial sea changed substantially in 2013 & 2014 compared to previous years as a result of changes to the management of the dredge fishery. In 2013 spatial restrictions for dredging were introduced i.e. dredging was restricted to a limited area (dredge box) and a specific TAC of 1,000t was allocated to the dredge fishery. In 2014 the same spatial restrictions were in place however, no specific TAC was allocated to the dredge fishery with landings instead considered as part of the overall TAC for the territorial sea. As the dredge fishery did not open until 1st October 2014 and the overall TAC was reached on 2nd October 2014 the 2014 fishery was closed with no reported dredge landings. As such, within the territorial sea in 2014 the proportion of landings caught by otter trawlers increased to 100% of total landings. Fishing effort (days spent fishing), within the three ICES rectangles 36E5, 37E5 and 38E5, increased sharply in 2010, 2011 and 2013 but, following a decline in stock status has substantially decreased again, for both Manx and UK vessels, in 2014 (Figure 13).

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 $year_i$ (58%) and 5 months in $year_{i+1}$ (42%).

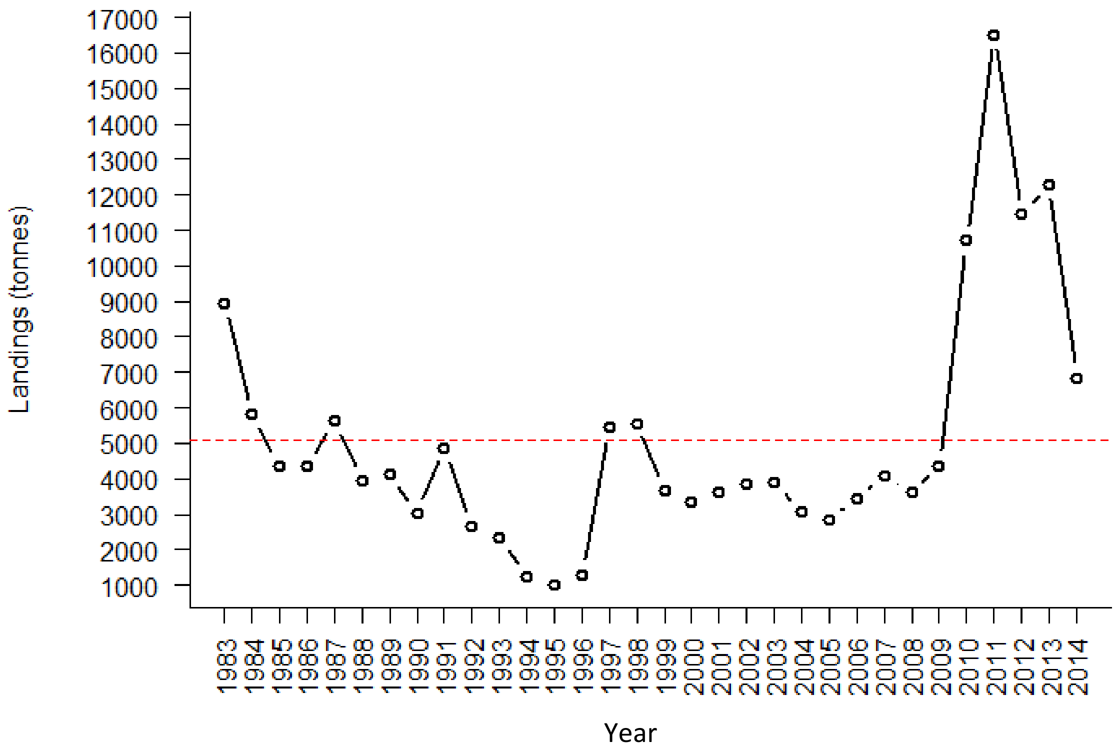

Figure 10: Landings (live weight) of queen scallops to the UK and Isle of Man. For comparison, the long-term average landings (1983 – 2015) of 5068t is marked on the graph by a dotted red line. Landings are referenced to ICES statistical rectangles 36E5 and 37E5 (as a proxy for territorial sea landings) 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 are for calendar years (Jan. to Dec.) Data source: Isle of Man Government, DEFA and iFISH.

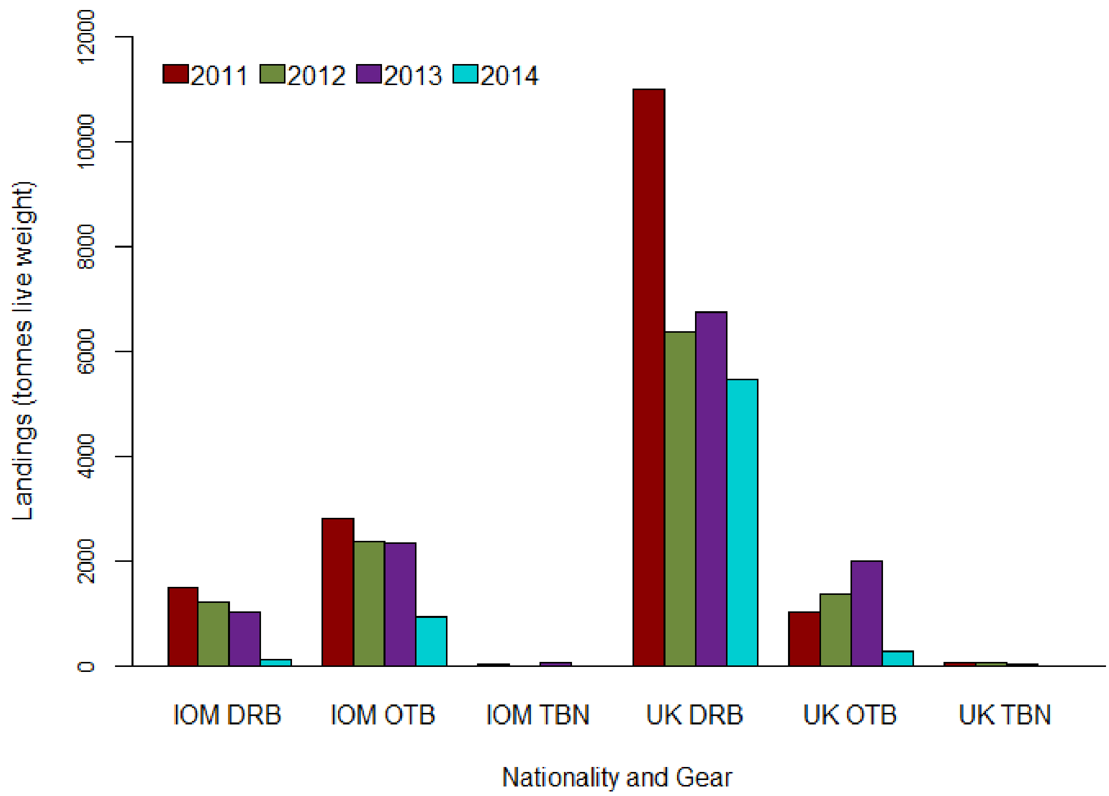

Figure 11: Landings from 36E5 and 37E5 by UK and Isle of Man (IOM) dredgers (DRB), queen scallop trawlers (OTB) and *Nephrops* trawlers (TBN). Data are derived from the iFISH database and DEFA and are for calendar years (Jan. to Dec.) rather than fishing years.

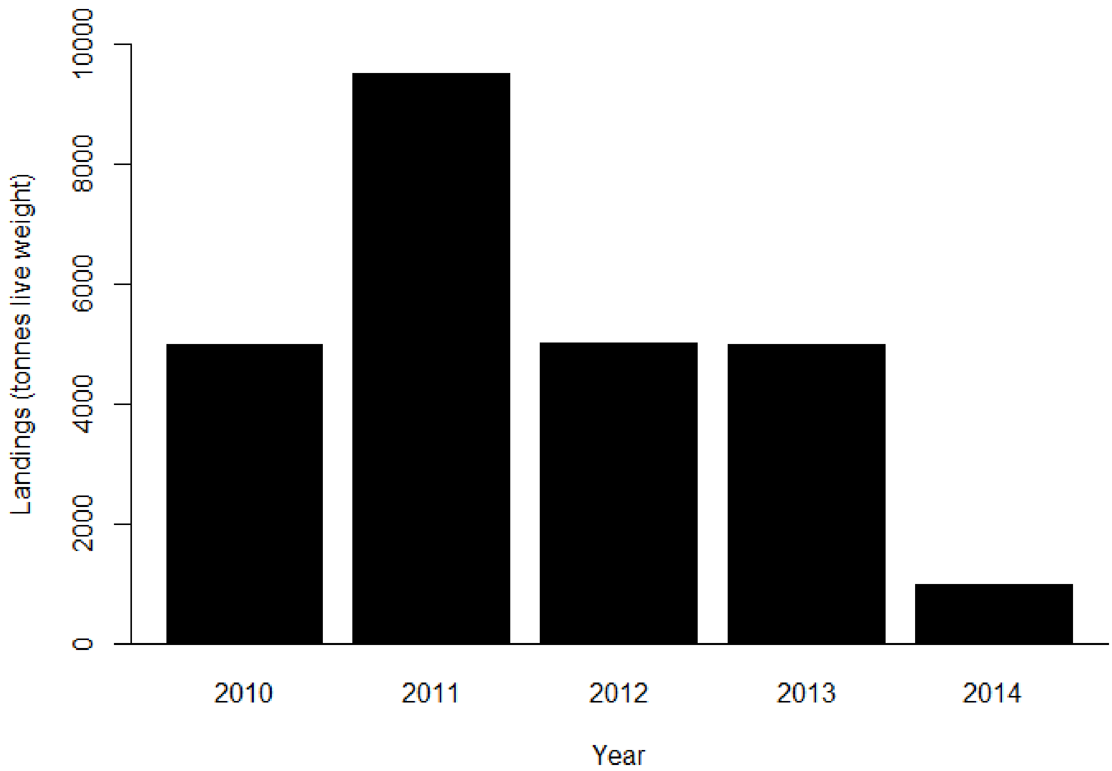

Figure 12: Estimated landings from the Isle of Man's territorial sea. These estimates are derived from VMS data combined with logbook data and include only data where matches were found between logbooks and VMS records. Data are for calendar years (Jan. to Dec.) rather than fishing years.

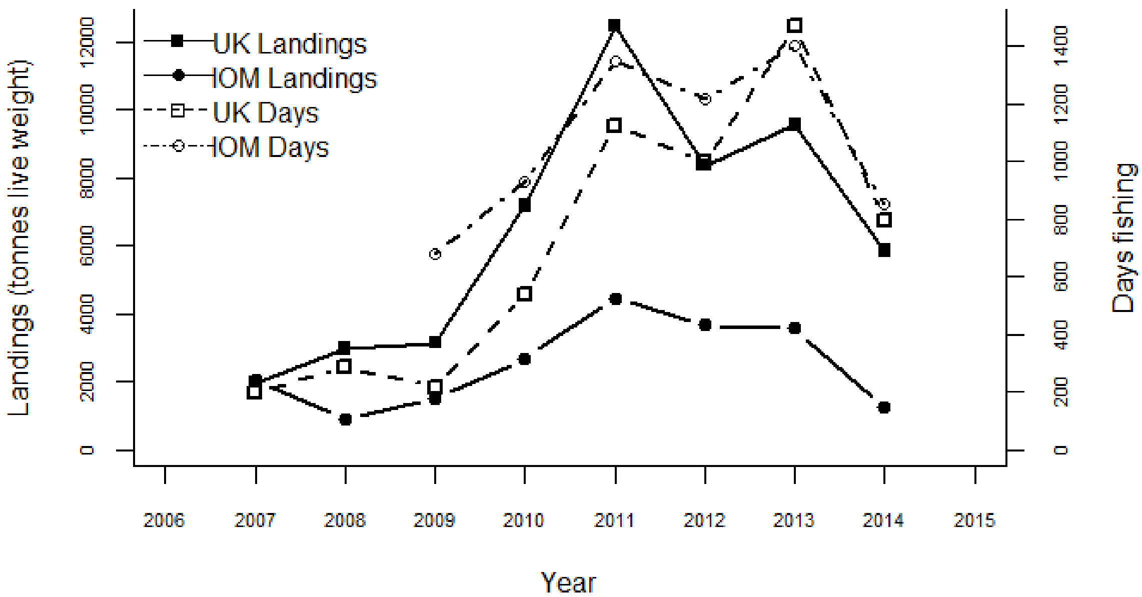

Figure 13: Landings from ICES statistical rectangles 36E5, 37E5 and 38E5 and days spent fishing for queen scallops by UK and IOM vessels. Days spent fishing by Isle of Man vessels are shown only from 2009 due to difficulty in accessing these data for earlier years. Data are derived from the iFISH database and are for calendar years (Jan. to Dec.) rather than fishing 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, while fishing mortality remained relatively stable in 2012, it has increased again in 2013 and declined in 2014 (Figure 14). Abundance of both recruits and post-recruits decreased between 2010 and 2013 (Figure 16 and Figure 17). Abundance of post-recruits continued to decrease between 2013 and 2015 (Figure 17), while recruit abundance showed a slight increase from 2013 to 2014 and declined again in 2015 (Figure 16). Following five years of increasing biomass (2006-2010), total biomass has decreased during each of the past five years (Figure 15 and Figure 18), as landings have remained high despite annual decreases in biomass. As landings exceeded surplus production in each of these five years a corresponding decline in biomass is evident for 2011 to 2015 (Figure 18).

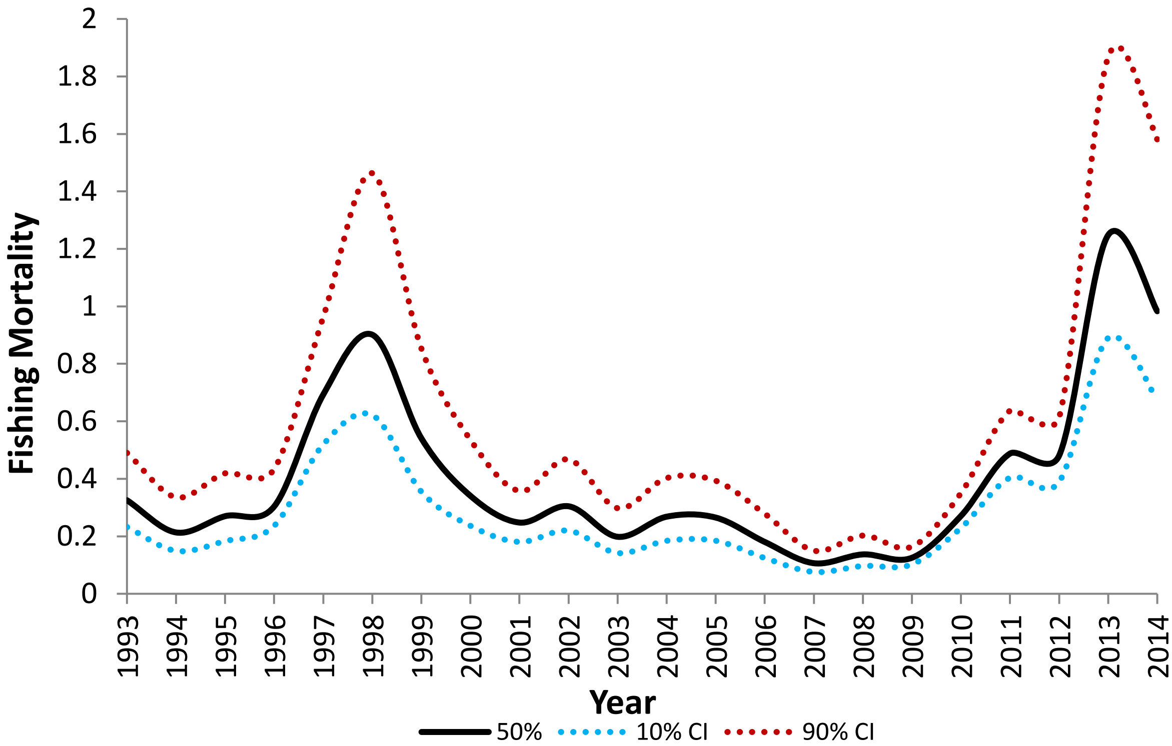

Figure 14: Fishing mortality for the stock assessment unit (ICES Rectangles 36E5 and 37E5) estimated from harvest rate. Values are for fishing years (June to May).

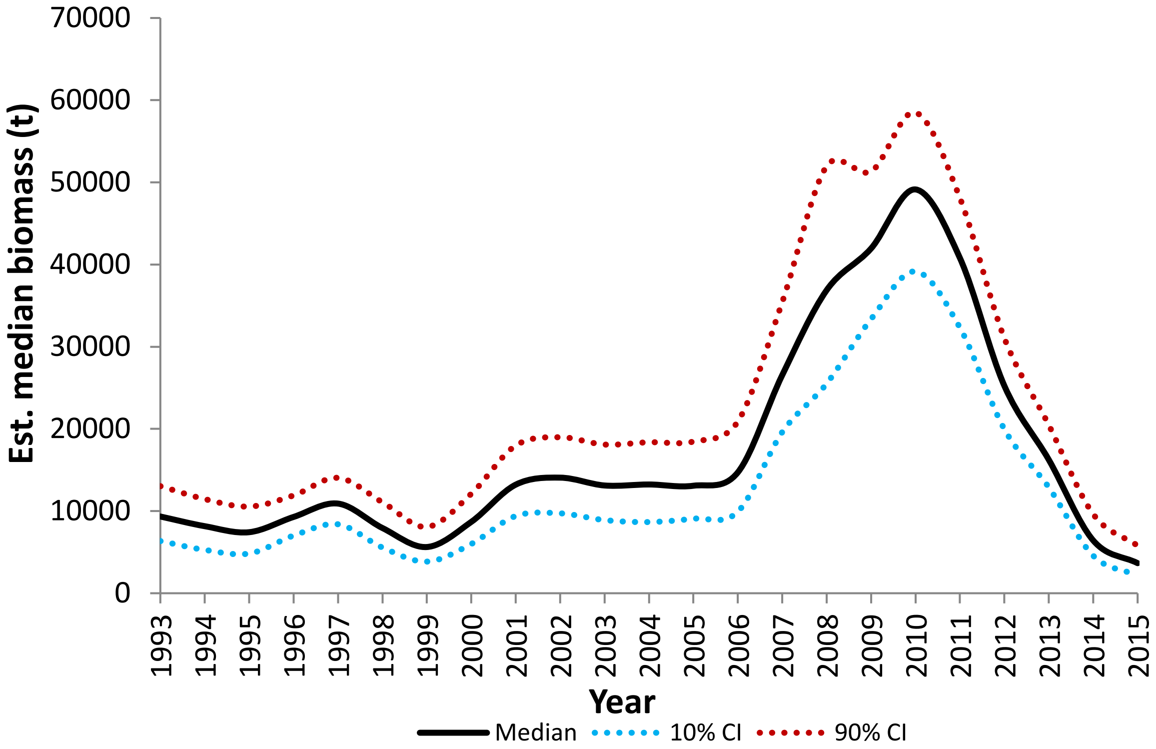

Figure 15: Total estimated biomass for the stock assessment unit (ICES Rectangles 36E5 and 37E5) bootstrap results.

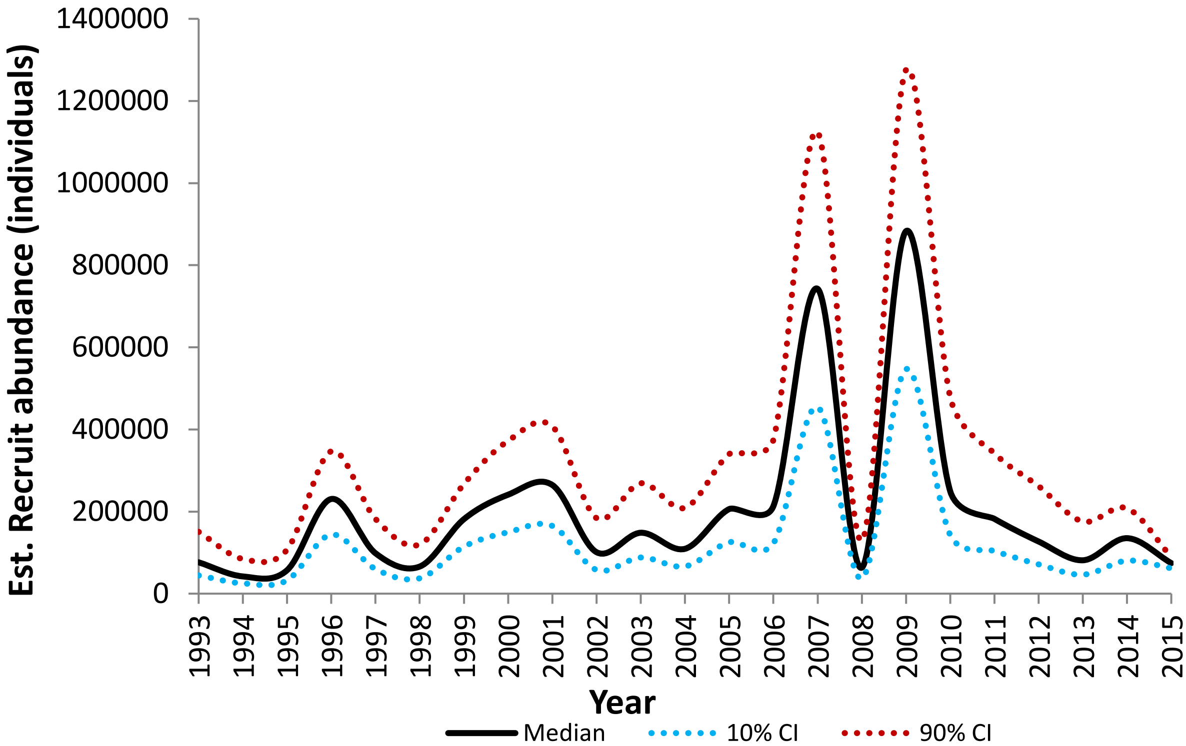

Figure 16: Estimated recruit abundance from the stock assessment unit (number of individuals).

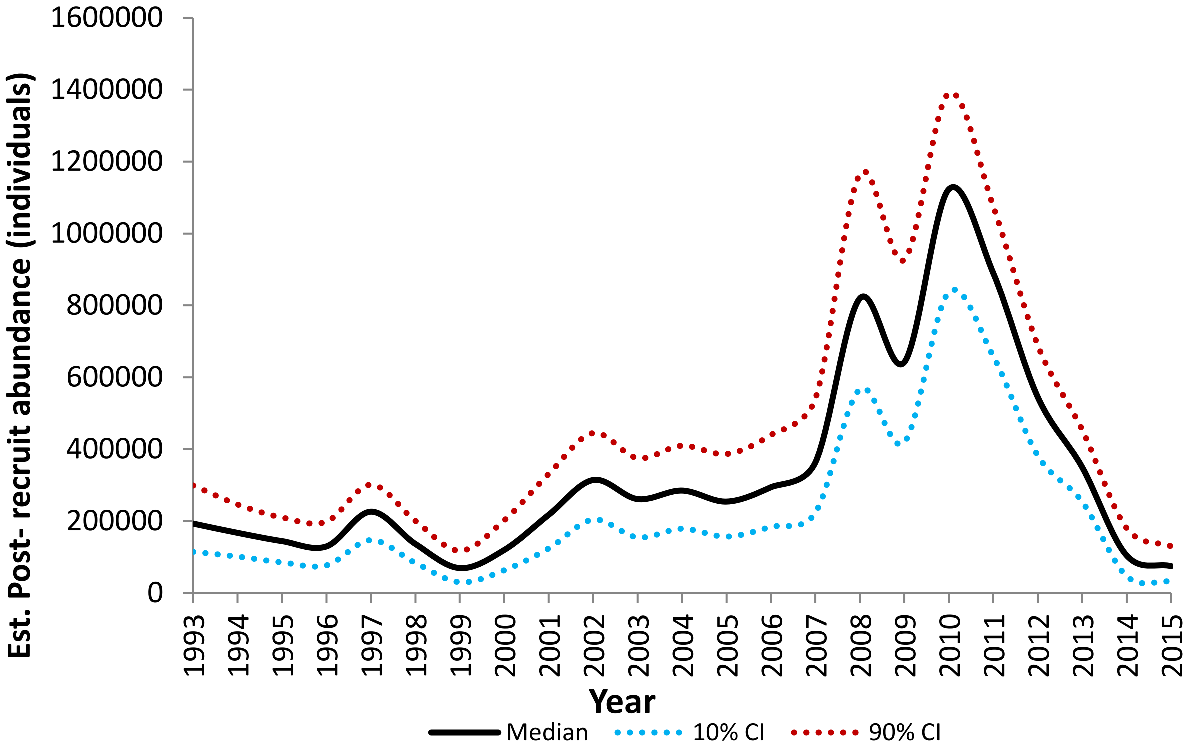

Figure 17: Estimated post-recruit abundance from the stock assessment unit (number of individuals).

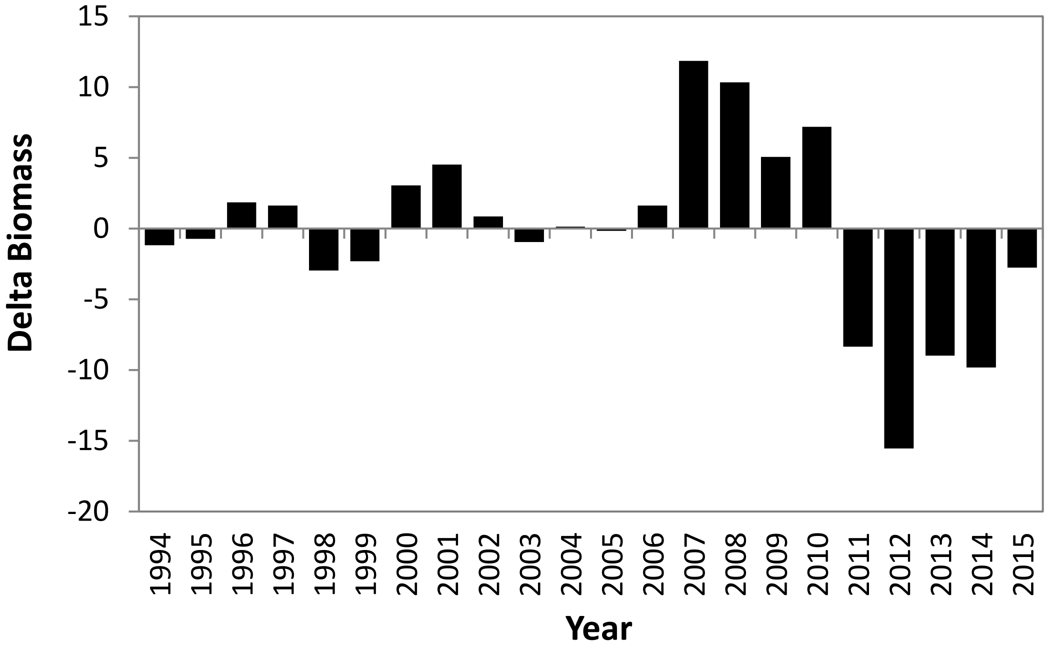

Figure 18: A graph showing annual change in total biomass (delta biomass) for the stock assessment unit (1000s tonnes). A negative delta biomass indicates that landings exceeded surplus production.

3.4 Closed Areas

Four closed areas were established at separate locations around the Island (Figure 4) with the primary purpose of ensuring that some areas of queen scallops, at high enough densities to spawn successfully (i.e. source areas) were safeguarded during the 2014/2015 fishing season. The veliger larvae produced from any successful fertilisation events will be transported to different locations around the Isle of Man's territorial sea (and outside of the 12nm limit) (i.e. sink areas) within the planktonic layer for a period of approximately 3 to 4 weeks. Protecting these interconnected areas which contain high densities of larger, post-recruits should result in higher levels of successful fertilisation, and subsequent spat delivery to surrounding fishing grounds. However, given the difficulties associated with sampling the abundance and origin of pre-recruit scallops (≤ 25 mm); several years of monitoring will be required to give an indication of whether recruitment around the Island is improving.

In order for closed areas to be effective for managing short lived species like queen scallops (which rarely live longer than 5-6 years or grow more than 90mm) it is important to monitor the annual distribution (e.g. size frequency) of the populations within them. For example, in Closed Area I which is situated to the west of the Island (Figure 4), the population sampled in 2014 was almost entirely composed of individuals of a single size class of 50 – 60mm (shell height) which are large, post-recruit individuals which will produce greater quantities of eggs per individual than smaller scallops (Figure 19). By closing these areas, these scallops will have had the opportunity to spawn during spring and autumn 2014 and should spawn again in spring 2015. Following a year's additional growth the population sampled in 2015 had increased in both size (Figure 19) and yield (Table 1) compared to 2014 and was composed almost entirely of a single size class of 60 – 70mm (shell height) which are nearing the end of their natural life cycle (Figure 19). In addition, since the closure the abundance of queen scallops within this closed areas had shown an initial increase from 2014 (average of 48.9 scallops per 100m^2) to 2015 (average of 73.5 scallops per 100m^2).

In Closed Area II, situated to the south of the Island (Figure 4), the population sampled in 2014 and 2015 both showed a good size range of individuals, with the largest proportion within the two size classes 50-60mm and 60-70mm; providing an ongoing source of large, post-recruits for spawning (Figure 19). In addition, the abundance of queen scallops within this closed area had also shown an initial increase from 2014 (average of 7.6 scallops per 100m^2) to 2015 (average of 13.2 scallops per 100m^2).

In Closed Area IV, situated to the north of the Island (Figure 4), the population sampled in 2014 and 2015 showed a good size range of individuals, with the largest proportion within the two size classes 50-60mm and 60-70mm; providing a source of large, post-recruits for spawning (Figure 19). However, although the overall abundance of queen scallops within this closed area had not shown any initial increase from 2014 (average of 24.2 scallops per 100m^2) to 2015 (average of 16.7 scallops per 100m^2); the proportion of recruits within this closed area had increased from 2% (2014) to 6% (2015).

In Closed Area III, situated to the east of the Island (Figure 4), the population sampled in 2014 and 2015 was composed predominately of larger, post-recruits from 50 – 80mm; providing a source of large, post recruits for spawning (Figure 19). Closed Area III was, however, the only closed area that did not show an increase in either total overall abundance or proportion of recruits overall abundance. The population sampled in 2015 in fact showed a decrease in the proportion of scallops in the latter size classes (70 – 90mm) (Figure 19), which were near the end of their natural life cycle, but no new recruits have come through to replenish the stock in this area.

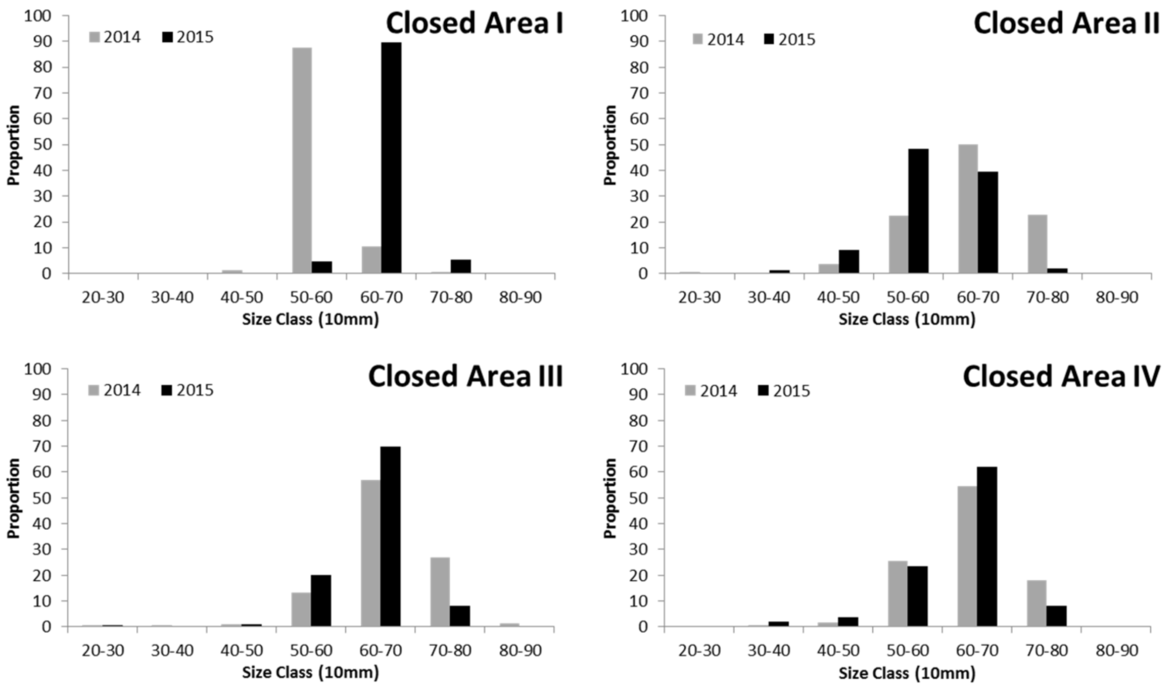

Figure 19: A comparison of size frequency (proportion) of scallops surveyed in the 2014 and 2015 spring scallop survey within closed areas.

Table 1: Isle of Man data indicating the average no. of queen scallop meats and queen scallop meats plus roe per kilogram. The data was collected during 2011 and 2013 spring and autumn scallop abundance surveys.

Size class 10 mm (shell height)	Av. Meats kg^{-1}	Av. Meats + Roe kg^{-1}
40 – 50	455	398
50 – 60	229	181
60 – 70	142	112
70 – 80	119	97
80 – 90	93	73

3.5 Stations outside of the territorial sea

During this first year of sampling outside of the Isle of Man's territorial sea, data remains limited and should be interpreted with caution. However, Figure 20 provides a general indication of the stock abundance at sites surveyed inside and outside of the territorial sea for three of the main fishing grounds. At stations at POA and TAR observed densities were higher inside the territorial sea compared to outside, whilst at EDG densities were similarly low both inside and outside the territorial sea.

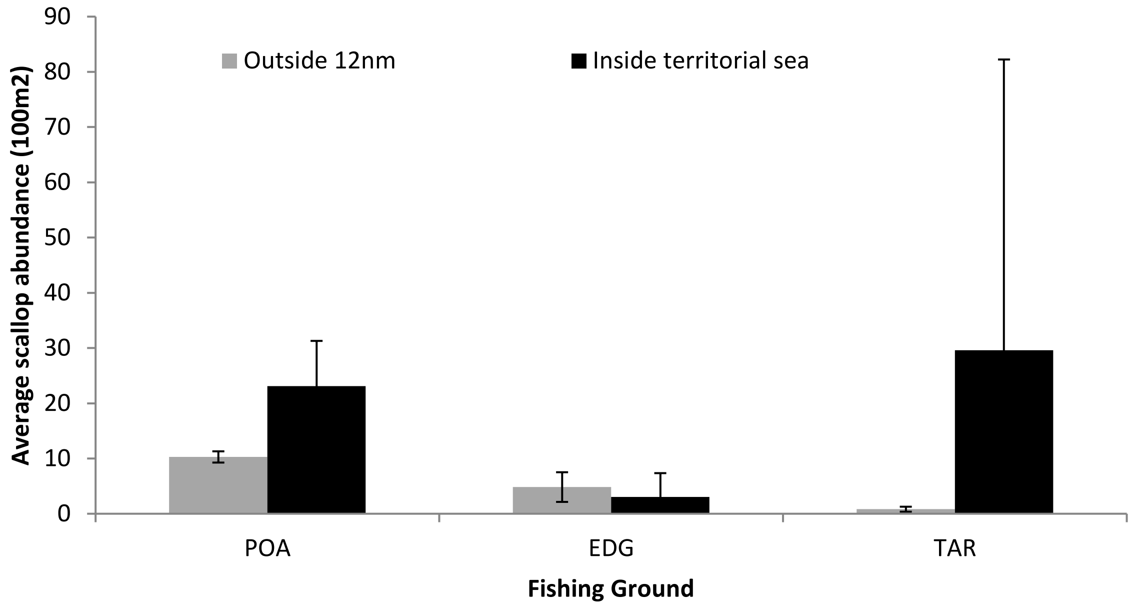

Figure 20: A summary of the average abundance of queen scallops (from queen scallop dredges) from stations surveyed inside and outside the territorial sea for each of the three main fishing grounds. During this first year of initial surveying a limited number of sites were sampled outside of the 12nm limit (POA: n = 2; EDG: n = 3; TAR: n= 2) compared to inside the territorial sea (POA: n = 4; EDG: n = 18; TAR: n= 6).

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 1995. However, relatively low exploitation levels during the period 2000 to 2010 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 (Figure 5) 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 proportion of effort is undertaken using otter trawls, while over the wider stock assessment 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). Irrespective of values of *M* or *s* used the trends of biomass are consistent between models. It is on these trends that recommendations for TACs are based.

When total biomass has been maintained at around 13000t or higher and around 25% of biomass has been removed annually the fishery has experienced both increases and decreases in total biomass, reflecting the fishery's dependence on annual recruitment. The largest increases in biomass occurred where biomass was >13000t. Therefore, 13000t is recommended as a critical minimum threshold for biomass. Furthermore, there is no evidence that the population reached carrying capacity at biomass of 49000t, 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, when biomass is above the recommended minimum critical threshold (i.e. 13000t), removing more than 30% of queen scallop biomass increases the risk that the stock will be depleted (Murray, 2013). 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 (Murray, 2013). The median estimated biomass in 2015 is 3656t (with a 10% and 90% confidence interval range of 2164t to 5777t, respectively). The inclusion of each additional year of data can lead to a slight retrospective change in the biomass estimate for the years prior. For example, the estimate for 2014 biomass has increased from 4708t to 6429t; this adjustment remains within the 10% and 90% confidence intervals for the previous year's predictions of stock biomass which ranged from 2604t – 8286t respectively.

Landings from within the territorial sea were greatly reduced during the 2014/2015 fishing season due to the implementation, monitoring and enforcement of management measures that were introduced during the fishing season and included a limited TAC of 1000t. However, landings across the entire stock assessment unit, which includes the area outside of the Isle of Man's territorial sea where at present the only management measure in place is a minimum landing size of 40 mm, have also substantially reduced from 2013 they still far exceeded surplus production causing a decline in biomass (Figure 18), and remain above the long-term average (1983 - 2013), which has contributed to the further decline in estimated biomass for 2015. The median population biomass (3656t) is now estimated to be at its lowest level since scientific surveys began in 1992. When it was last at a similarly low level in 1999 (5114t), it took a further 3 years before the population size increased to above 13000t. This means that the present low biomass situation may not start to improve for a number of years. The depletion of biomass beyond the recommended critical minimum threshold for biomass of 13000t means that the stock is now considered to be below the level at which future recruitment will be impaired. Given that the principles of the MSC certification scheme promote sustainable stock status it is not possible to recommend a scientifically advised TAC for ICES Rectangles 36E5 and 37E5 in the 2015/2016 fishing season. In order to promote the earliest return of the stock to above the minimum biomass limit it is recommended that no fishing occurs within the stock assessment unit. Fishery closures, low TACs or other management options may therefore need to be considered for several consecutive years.

These recommended thresholds (e.g. critical minimum threshold for biomass of 13000t) are subjective and can be used by fisheries managers as a guide in implementing management measures for the fishery. However, 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 severely depleted biomass. Furthermore, the queen scallop fishing fleet has the capacity to increase fishing effort very quickly as evidenced by the increase in fishing effort between 2009 and 2011; however, following a public consultation in late 2014/early2015 the issue of latent effort capacity within the fleet has now largely been addressed (see Section 4.7). Despite its dependence on scallops recruiting in their second year of growth, the fishery has been historically resilient to collapse.

Table 2: A comparison of scientific advice and actual TAC/landings (2011-2015). Landings here are represented seasonally (1st June to 31st May), with landings for 2014/2015 only available from 1st June to 30th April. BM = biomass. [*The recommended scientific TAC is proposed for two ICES squares (36E5 and 37E5), historically around 50% of landings have come from within the territorial sea and 50% from outside the territorial sea, therefore a TAC of 5000t for both ICES squares equates to a TAC of 2500t for the territorial sea].

Year	Estimated BM (36E5 & 37E5)	Scientifically advised TAC (36E5 & 37E5)	Scientifically implied TAC (territorial sea)*	Actual TAC (territorial sea)	Actual landings (36E5 & 37E5)	Estimated BM Removed (%)	Proportion of total landings taken from within territorial sea
2011/2012	40792t	-	-	-	15457t	38%	-
2012/2013	25244t	5000t	2500t	3500 – 4000t	9798t	39%	41%
2013/2014	16249t	5000t	2500t	5000t	11940t	73%	42%
2014/2015	6429t	None	None	1000t	5626t	87%	18%
2015/2016	3656t	None	None				

It is important to note the large increase in biomass that was observed from 2006 to 2011 (Figure 15) occurred following a period of three years (2002 – 2004) when landings slightly exceeded surplus production (Figure 18). 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.

There are several areas where further work can help to verify or improve data quality. Aspects that can be refined with additional work include natural mortality, 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. 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. In 2014 DEFA initiated a pan-Irish Sea working group and strategy to work towards future management of queen scallops at a level that incorporates the boundaries of the actual biological stock and not arbitrary management boundaries (see Section 1.3).

4.3.1 CSA Version Updates

To date all stock assessments have been undertaken using CSA version 3.1.1. (NOAA, 2008). However, as of 2014 an updated version of the stock assessment software, CSA version 4.3 (NOAA, 2014), became available. The main differences in these two package versions are that the new model uses maximum likelihood rather than weighted sums of squares to estimate parameters and also uses Baranov's catch equation exclusively to simulate the population (NOAA, 2015). In addition users can now supply the model with multiple surveys and survey types and specify the time of year that each survey occurred (NOAA, 2015). Within the appendices of this report the outputs of the two model versions are detailed (Appendix, 2, 3 and 4). A comparison of these outputs reveals that whilst the new model (version 4.3) consistently estimates biomass at a slightly higher value than the old model (version 3.1.1.), these values remain within the 10% and 90% confidence interval predictions for the old model and more importantly the trends in biomass remain constant between the two models.

4.4 Recruitment

The purpose of maintaining the biomass of queen scallops above a biomass reference point is to reduce the dependence of the fishery on annual recruitment. As biomass is now estimated to have fallen well below the recommended biomass reference point of 13000t, the stock (and associated fishery) is likely to be highly dependent on annual recruitment success to replenish the catchable biomass. Recruitment of queen scallops can, however, be highly variable and is affected by a range of complex and interacting factors including, but not limited to, temperature (Dickie, 1955; Fogarty, 1988; Mackenzie and Köster, 2004), food availability (Jackson *et al*., 1995), indirect fishing mortality (Shepard and Auster, 1991), currents, salinity (Nell and Holliday, 1988; Laing, 2002), spawning stock biomass, predation, substratum type (Stokesbury and Himmelman, 1995), predation and competition (Thouzeau, 1991). Annual variations in these factors can result in large fluctuations in recruitment and thus in the stock biomass and associated landings. In order to ensure that the stock and fishery is robust to such fluctuations in recruitment it is essential that the stock is rebuilt and maintained at a level above the recommended biomass reference point.

4.5 Stock assessment unit

In order to help redress the fundamental mismatch between the management unit (Isle of Man territorial sea), the stock assessment unit (currently ICES rectangles 36E5 and 37E5; but also looking to extend it out to 38E5) and the biological stock (Irish Sea), we highlight three approaches (short, medium and long-term) that will help to enable the stock assessment to be undertaken at the appropriate geographic, biological and management scale in the future.

Short Term: The first approach is to increase the extent of the current stock assessment model to all three ICES rectangles that cover the Isle of Man's territorial sea. The current stock assessment unit incorporates the two ICES rectangles 36E5 and 37E5; however, ICES rectangle 38E5 also extends into the Isle of Man territorial sea and so work has begun to incorporate data from survey stations and landings from this ICES rectangle into the stock assessment model (Appendix 3 and 4). Surveys were first undertaken in 38E5 in 2008 and so we now have 8 years of survey data that can be incorporated into the model. Although only a single station (Historical Station POA) has been surveyed in most years, in both 2014 and 2015 three survey stations (Station POA, 10 and 45) were all surveyed. For the stock assessment, landings for 38E5 were estimated from June to May up to 2008 and calculated thereafter as has been the case for landings from both 36E5 and 37E5 for the existing model. A stock assessment model (Revision 1) was run that incorporated ICES rectangle 38E5 into the current model for 36E5 and 37E5, using both versions of CSA (v3.1.1 and 4.3), (Appendix 3). In all models the trend in biomass remains the same, but the biomass estimate increased by an average of 1300t when ICES rectangle 38E5 was incorporated into the stock assessment model.

Medium Term: Temporal, financial and administrative restrictions have meant that the stock abundance survey has traditionally been conducted only within the areas of the ICES Rectangles that fall within the Isle of Man territorial sea and not in the areas that fall outside it (i.e. outside the Isle of Man 12 nm limit). However, additional survey time during the 2015 stock abundance survey, as a result of the cessation of the autumn survey, meant that it was possible to apply for permission from the relevant UK jurisdictions to undertake survey tows outside of the Isle of Man 12 nm limit. Following a scallop subgroup meeting of the Isle of Man scientific steering committee a list of potential survey sites, for both king and queen scallop stocks, was provided by local industry (Figure 2). As we have only one year of data for the sites outside of the 12nm limit it is not yet feasible to run an accurate stock assessment model that incorporates this new data. In addition, as the suggested sites were locations indicated by fishermen of high density fishing areas it would not be appropriate to incorporate or directly compare these with the stations within the territorial sea that are based on a standardised grid. However, they do provide a general indication of queen scallop densities outside of the territorial sea compared to inside (Section 3.5). Going forward, in order to enable the incorporation of survey stations outside of the 12nm into the stock assessment model, which will help ensure the abundance index is truly representative of the stock size, it is important that sites outside of the Isle of Man's 12nm limit continue to be surveyed so that this data can be added to the model. However, the stations selected for surveying will need to be selected in a similar manner (i.e. standardised grid) in order for them to be incorporated into the model. In addition since July 2013, the Agri-Food and Biosciences Institute (AFBI) in Northern Ireland has also begun undertaking surveys of queen scallops within areas of the Irish Sea, as such coordinating survey effort with AFBI may enable a better coverage of the wider stock to be achieved.

Long Term: Finally, as discussed already in this report a longer-term objective for the management of the fishery is to develop an approach that will enable the stock assessment and management units to be matched to the area encompassed by the actual biological stock (i.e. Irish Sea), through development of a Pan-Irish Sea management approach. Work towards this involves multiple management jurisdictions (Section 1.3).

4.6 Spatial management and closed areas

As discussed in Section 4.1, because scallops are broadcast spawners, successful reproduction is likely to be higher when adults are present at higher densities with fertilisation success limited if local densities drop below some threshold level as a result of Allee effects. Therefore, spatial management (e.g. closed areas) may be particularly important as a mechanism by which to maintain sufficient densities, in at least some areas, to ensure successful fertilization, recruitment and long-term viability of the fishery. In addition, closed areas could also provide effective control of fishing effort in habitats that are easily damaged by fishing activity and that may be important for spat settlement and recruitment as discussed in Section 4.2. In order to inform management decisions on the siting of closed areas an in-depth understanding of scallop recruitment mechanisms is essential to ensure the protection of recruitment sources rather than sinks.

As discussed in Section 2.3 it will likely take several years before the impact of the closed areas can be properly assessed. However, initial results from monitoring during the 2015 scallop abundance survey have indicated a generally positive response with the total abundance, or abundance of recruits increasing from 2014 to 2015 in three out of the four closed areas. There was no initial increase (total abundance or recruit abundance) observed in the remaining closed area (Closed Area III) situated to the east of the Island (Figure 4). There are two possible explanations for the decline in abundance within this closed area. Firstly, the survey sites which indicated relatively high abundances during the 2014 spring scallop survey were located at the edge of the closed area. During the 2014/2015 fishing season the edge of the closed area was fished intensively. As queen scallops are known to swim and move in response to physical disturbance it is possible that the queen scallops moved to areas outside of the closed area and were subsequently removed by fishing activity. Secondly, no increase was observed in the proportion of recruits within the closed area which may mean that there has not been sufficient recruitment coming into the area over the previous two or three years to replenish the stocks as older scallops die off (at the end of their natural life cycle). As discussed in Section 4.5, recruitment can be negatively impacted by a range of variables including environmental conditions, indirect fishing mortality and direct fishing mortality. In addition, as the sources of recruitment for the fishing grounds at the east of the Island are thought to be outside of the territorial sea (Neill & Kaiser, 2008), recruitment may also be negatively impacted by the large amount of fishing activity that occurs within these source areas.

4.7 Fishing effort

On the recommendation of the QMB, DEFA undertook a public consultation between December 2014 and February 2015 to try and resolve the issue of excessive effort within the fishery (in particular latent effort). The main purpose was to protect stock levels and to aid the rebuilding strategy for the queen scallop stock that is currently in place to achieve the recertification of this fishery within the MSC process. Based on the analysis of the public consultation results (DEFA, 2015) the QMB recommended to the Minister that eligibility for a queen scallop fishing licence within the Isle of Man territorial sea should be based on a track record of 20 days within the 2010 – 2012 (inclusive) queen scallop fishing seasons. This has in effect reduced the number of licenced vessels from 138 (2014) to 42 (2015), although at this time several pipeline cases are still under review.

4.8 Wider-scale issues

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 three years. The introduction of closed areas, increasing minimum landing size (to 55 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 available to allow the fishery to be managed to sustain or increase yields.

5. Conclusions

- Following a decline in stock status in 2014, and an estimated biomass below the level at which recruitment is considered to be impaired; the MSC certification for this fishery was suspended on May 19th 2014.
- The issue of latent effort within the fishery has now been partially addressed with a reduction in the number of eligible licenced vessels from 138 for the 2014/2015 fishing season to 42 for the 2015/2016 fishing season, following the introduction of a track record period (although several pipeline cases are currently under review).
- Given that the principles of the MSC certification scheme promote sustainable stock status, it is not possible to recommend a scientifically advised TAC for ICES Rectangles 36E5 and 37E5 in the 2015/2016 fishing season. In order to promote the earliest return of the stock to above the minimum biomass limit it is recommended that no fishing occurs within the stock assessment unit.
- Whilst landings have substantially decreased in 2014, particularly within the territorial sea (1000t) where management measures were in place, landings from the entire stock assessment unit (6429t) still exceeded surplus production.
- Biomass is likely to be depleted leading to the fishery becoming recruitment-dependent where >40% of biomass is removed annually. The 2014/2015 fishery removed 87% of the estimated mean biomass for 2014, leading to a further decline in estimated biomass in 2015.
- Four small areas that had exhibited sufficiently high abundances in the April 2014 survey were strategically closed around the Island. This was done to ensure that some scallops existed in high enough densities to spawn successfully and to try and promote improved recruitment to the fishery the following year.
- The 2015 estimated median population biomass (3656t) is at its lowest level since scientific surveys began in 1992. In 1999 when biomass was estimated at a similarly low level (5114t), it took a further 3 years before the population size increased to above 13000t. This indicates that the present low biomass situation may not start to improve for a number of years. Fishery closures, low TACs or other management measures may need to be in place for several consecutive years in order to let the biomass increase.
- Biomass depletion has rendered the fishery heavily dependent on annual recruitment. Management promoting successful spawning and recruitment using closed areas is essential. However, the siting, size and access status of closures should be considered annually.
- Low abundance of recruits at several survey stations require plans to increase sampling effort of queen scallop recruits during the spring scientific survey to be developed. Beam trawl sampling (which better targets recruits) should be regularly undertaken across the range of survey stations in parallel to the traditional stock assessment survey using dredges.
- Continuing to build on the additional survey work undertaken in April 2015, it will be essential that future annual scientific abundance surveys samples at additional stations outside of the 12nm limit, within ICES rectangles 36E5, 37E5 and 38E5, to help ensure the abundance index is truly representative of the stock size.
- The Irish Sea queen scallop fishery should be managed as a single biological stock with advice provided based on data collected across the Irish Sea. An initiative to achieve a pan-Irish Sea management approach for the queen scallop fishery was started by DEFA in 2014. It is vital that this important work, to achieve a collaborative management approach for queen scallop stocks within the Irish Sea, continues.

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7. Appendices

Appendix 1. Station sampling frequency

Table 3: The survey station sampling frequency for spring scallop surveys and extent of sampled sites; additional numbered survey stations for 2012, 2013, 2014 and 2015 are shown in a separate section of the table. 'X' indicates station surveyed in June; 'X' indicates site was not surveyed in June and data from the October survey prior was substituted (see Figure 3 for spatial locations). Stations used in the 2015 stock assessment model are highlighted in green.

Survey Year	BRI	BRO	CHI	EDG	LAX	MAG	OCA	PEL	POA	PSM	PSM20	RAM	SED	TAR	No. Sites surveyed
1992			X							X	X				3
1993				X						X	X		X		4
1994				X	X					X	X		X		5
1995			X	X	X					X	X	X	X		6 (+1)
1996	X		X	X	X					X	X		X		6 (+1)
1997				X	X					X	X		X		4 (+1)
1998			X	X	X					X	X		X		1 (+5)
1999			X		X					X			X		4
2000			X	X	X					X					4
2001			X	X	X					X					4
2002					X										1
2003			X	X	X					X					4
2004			X	X	X					X					4
2005			X	X	X										3
2006			X	X	X										3
2007	X	X	X	X										X	5
2008	X	X	X	X	X	X	X	X		X		X	X	X	12
2009	X	X	X	X	X	X		X	X	X		X	X	X	10 (+2)
2010	X	X	X	X	X				X	X		X	X	X	10
2011	X	X	X	X	X			X		X		X	X	X	10
2012	X		X	X	X				X	X		X	X	X	33 (See below)
2013	X	X	X	X	X			X	X	X		X	X	X	41 (See below)
2014	X	X	X	X	X			X	X	X		X	X	X	43 (See below)
2015	X	X	X	X	X			X	X	X		X	X	X	47 (See below)

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	44	45	48	50	51
2012	X				X	X	X					X		X	X	X	X	X	X	X	X	X				X			X	X	X	X	X	X	X	X	X						
2013	X	X	X	X	X	X	X	X				X		X	X	X	X	X	X	X	X	X				X	X		X	X	X	X	X	X	X	X	X	X					
2014	X	X	X	X	X	X	X	X		X		X		X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X	X		X		X	X			X	X		
2015	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X		X		X		X	X	X	X	X		X	X	X	X	X	X	X		X	X

Appendix 2. Original Model: data input and outputs for CSA version 3.1.1 and version 4.3.

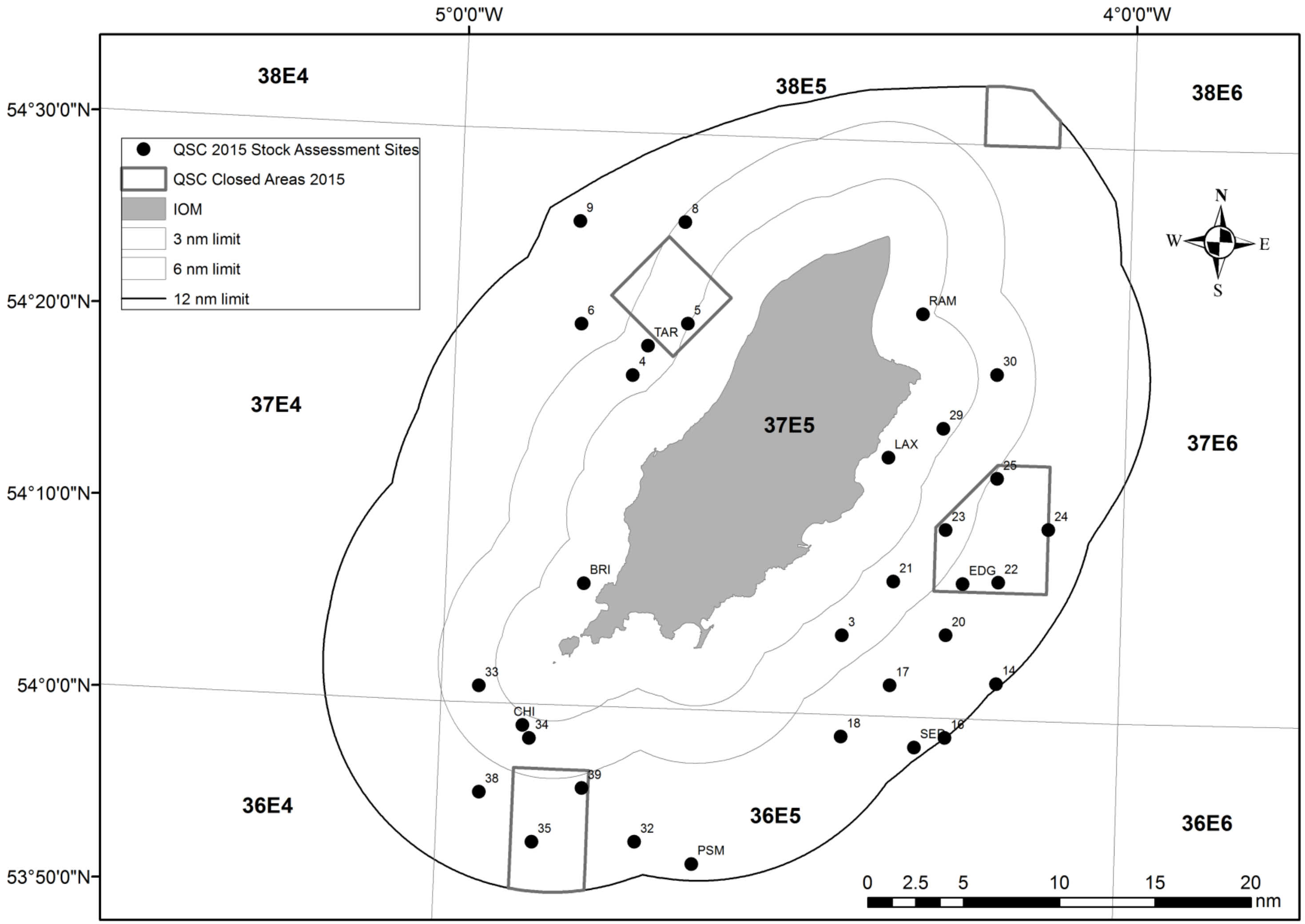

Figure 21: A map displaying only the actual survey stations within the Isle of Man territorial sea used in the original version of the 2015 queen scallop stock assessment model. For this stock assessment model the stock assessment unit covers the area of the two ICES rectangles 36E5 and 37E5.

Table 4: Input data for the original version of the 2015 queen scallop stock assessment model

	Survey				*Catch*				*Biological*	
	Survey Numbers		Weight per Individual		Catch Numbers		Weight per Individual		Natural Mortality	Recruit Selectivity
Survey Year	Recruits	Post-Recruits	Recruits	Post-Recruits	Landings	Discards	Landings	Discards		
1993	30.13425654	347.0402466	0.018731828	0.039115466	68.19107754	3.409553877	0.039115466	0.018731828	0.2	0.35
1994	15.86583449	174.5156615	0.018320125	0.043612203	36.31116884	1.815558442	0.043612203	0.018320125	0.2	0.35
1995	21.75212942	127.1489703	0.017112799	0.043411184	42.49930809	2.124965404	0.043411184	0.017112799	0.2	0.35
1996	46.91394182	77.46436025	0.01719857	0.03908781	85.09042077	4.254521039	0.03908781	0.01719857	0.2	0.35
1997	30.13695148	337.8036495	0.018163319	0.040178731	145.4841288	7.274206439	0.040178731	0.018163319	0.2	0.35
1998	31.46216705	355.6560054	0.014686001	0.050585348	108.3920667	5.419603337	0.050585348	0.014686001	0.2	0.35
1999	35.29379961	33.81202304	0.014428253	0.041645661	91.36577998	4.568288999	0.041645661	0.014428253	0.2	0.35
2000	114.2770179	250.3250707	0.017138573	0.035180334	93.58552423	4.679276212	0.035180334	0.017138573	0.2	0.35
2001	192.7072587	293.774687	0.018307718	0.037456937	93.57013095	4.678506547	0.037456937	0.018307718	0.2	0.35
2002	44.44380737	269.4850984	0.013478347	0.039649519	98.4609002	4.92304501	0.039649519	0.013478347	0.2	0.35
2003	106.7079497	411.692814	0.017501232	0.039875393	66.07860475	3.303930238	0.039875393	0.017501232	0.2	0.35
2004	87.83028495	507.586832	0.01406431	0.040071866	82.80223857	4.140111928	0.040071866	0.01406431	0.2	0.35
2005	224.3407131	108.3704358	0.017005674	0.036403412	94.59038368	4.729519184	0.036403412	0.017005674	0.2	0.35
2006	111.7935305	69.62017932	0.018102407	0.035319468	75.93400756	3.796700378	0.035319468	0.018102407	0.2	0.35
2007	242.4880336	157.6293945	0.016077647	0.039473075	97.2200671	4.861003355	0.039473075	0.016077647	0.2	0.35
2008	20.98381277	380.4426363	0.0141	0.0436	99.61156346	4.980578173	0.0436	0.0141	0.2	0.35
2009	121.7941784	820.3630634	0.0186	0.0385	158.3406277	7.917031385	0.0385	0.0186	0.2	0.35
2010	59.32195154	940.4026064	0.0136	0.0401	293.5165586	14.67582793	0.0401	0.0136	0.2	0.35
2011	40.94383456	607.0882194	0.016	0.0424	364.5518868	18.22759434	0.0424	0.016	0.2	0.35
2012	32.19074825	781.8442872	0.015085937	0.042655861	229.698798	11.4849399	0.042655861	0.015085937	0.2	0.35
2013	24.33971943	457.142442	0.014506188	0.042748631	279.30719	13.9653595	0.042748631	0.014506188	0.2	0.35
2014	31.95472078	110.7910124	0.015672785	0.042058611	133.7657117	6.688285586	0.042058611	0.015672785	0.2	0.35
2015	26.58036197	91.86069708	0.016656	0.032924	-	-	0.032924	0.016656	0.2	0.35

Table 5: Summary of results from Catch Survey Analysis model (Version 3.1.1) with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	76.3651	193.118	0.3255	9336
1994	41.9362	167.235	0.2134	8157
1995	57.0578	144.281	0.27	7429
1996	230.568	129.47	0.3038	9286
1997	98.4698	226.169	0.6929	10908
1998	66.0055	136.48	0.9013	7936
1999	181.48	69.2542	0.5411	5625
2000	241.039	119.626	0.3408	8685
2001	264.62	217.385	0.2478	13214
2002	100.962	314.252	0.3045	14067
2003	148.381	261.085	0.1983	13112
2004	109.193	284.849	0.2682	13234
2005	205.986	254.228	0.2652	13081
2006	213.299	294.177	0.1803	14705
2007	742.45	363.436	0.1064	26545
2008	63.3573	819.56	0.137	36881
2009	882.845	641.96	0.1253	41951
2010	249.276	1,122.89	0.2711	49137
2011	182.116	889.95	0.488	40792
2012	126.955	545.321	0.4809	25244
2013	81.2775	350.028	1.2481	16249
2014	135.144	104.534	0.983	6429
2015	74.3585	74.6603	-	3656

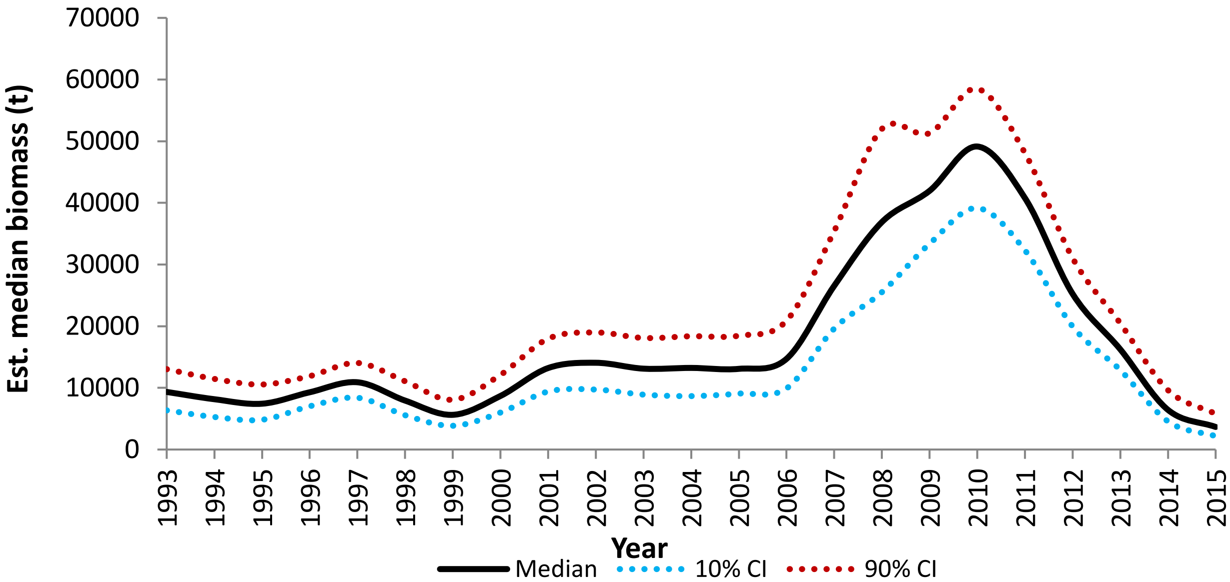

Figure 22: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5 and 37E5) bootstrap results. (CSA Version 3.1.1)

Table 6: Summary of results from Catch Survey Analysis model (version 4.3) with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	86.8003	258.1095	0.25904	11724
1994	46.6271	218.0025	0.17259	10359
1995	65.8311	182.349	0.22024	9043
1996	268.5345	163.284	0.25773	11005
1997	132.3835	273.171	0.52873	13387
1998	87.9815	195.8095	0.57744	11199
1999	164.6015	130.4815	0.44087	7811
2000	296.432	155.294	0.2727	10549
2001	319.561	281.906	0.19817	16419
2002	115.628	404.243	0.24694	17589
2003	178.4835	332.61	0.16201	16400
2004	130.61	356.0615	0.21974	16105
2005	234.392	320.1155	0.22068	15644
2006	232.8835	364.259	0.15922	17095
2007	806.97	417.271	0.09635	29480
2008	70.7628	910.34	0.12458	40708
2009	910.85	709.73	0.11923	44358
2010	286.1875	1,181.06	0.26119	51262
2011	225.953	925.58	0.44903	42893
2012	139.4315	603.0555	0.4375	27809
2013	88.3102	392.3675	1.07568	18052
2014	127.894	134.2165	0.8721	7652
2015	76.122	89.7946	-	4228

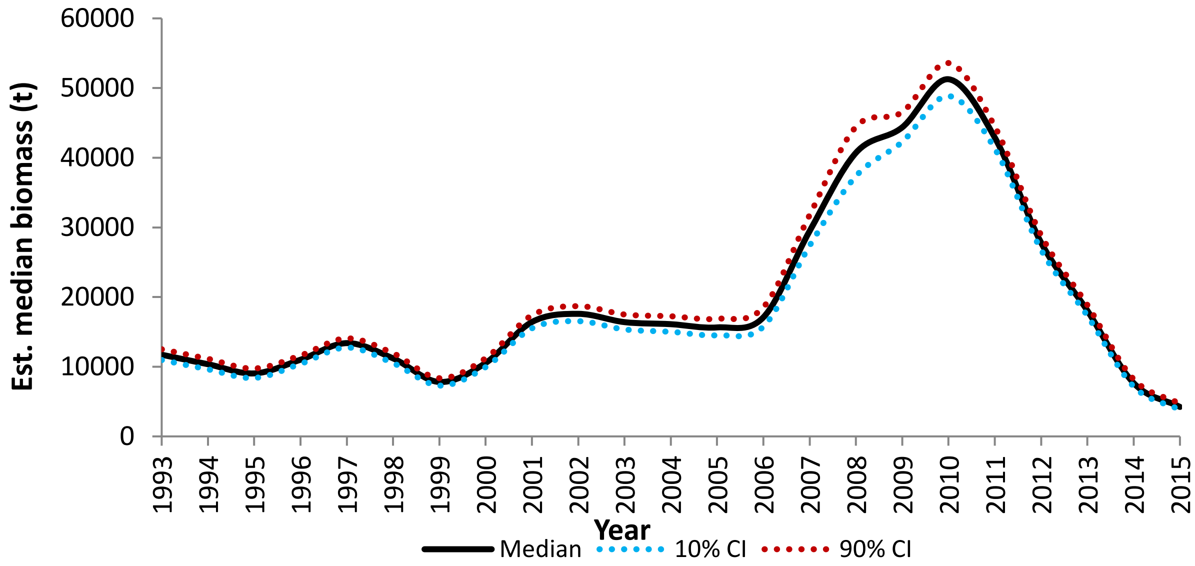

Figure 23: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5 and 37E5) MCMC results. (CSA Version 4.3)

Appendix 3.Revised Model 1 (Includes 38E5): data input and outputs for CSA version 3.1.1 and version 4.3.

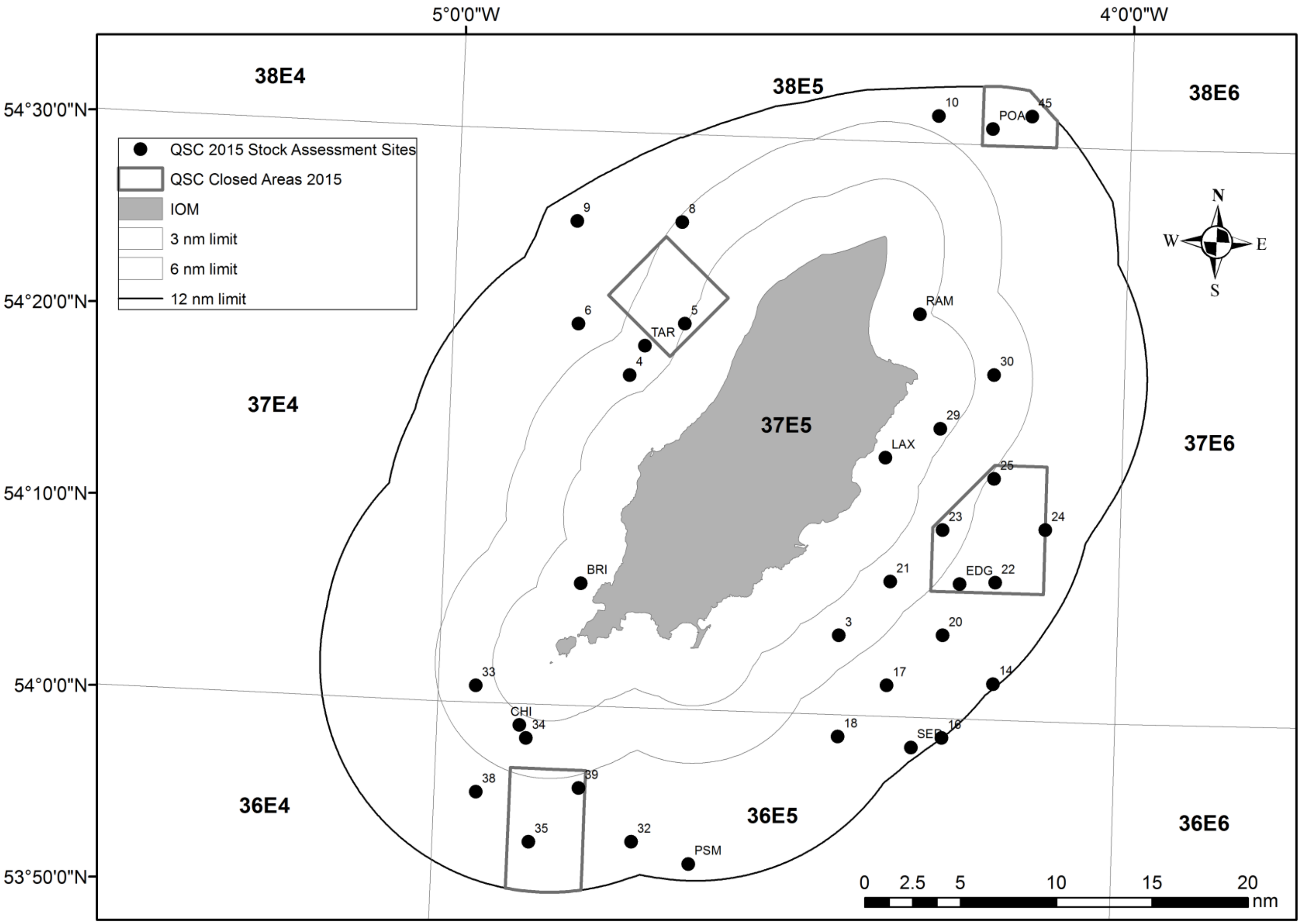

Figure 24: A map displaying only the actual survey stations within the Isle of Man territorial sea used in the revised version 1 of the 2015 queen scallop stock assessment model. For this stock assessment model the stock assessment unit covers the area of the three ICES rectangles 36E5, 37E5 and 38E5 (Stations POA, 10 and 45).

Table 7: Input data for the revised version 1 of the 2015 queen scallop stock assessment model

	Survey				*Catch*				*Biological*	
	Survey Numbers		Weight per Individual		Catch Numbers		Weight per Individual		Natural Mortality	Recruit Selectivity
Survey Year	Recruits	Post-Recruits	Recruits	Post-Recruits	Landings	Discards	Landings	Discards		
1993	30.13426	347.0402	0.018731828	0.039115466	76.08161921	3.80408096	0.039115466	0.018731828	0.2	0.35
1994	15.86583	174.5157	0.018320125	0.043612203	40.62975081	2.03148754	0.043612203	0.018320125	0.2	0.35
1995	21.75213	127.149	0.017112799	0.043411184	47.38438214	2.369219107	0.043411184	0.017112799	0.2	0.35
1996	46.91394	77.46436	0.01719857	0.03908781	96.60382917	4.830191459	0.03908781	0.01719857	0.2	0.35
1997	30.13695	337.8036	0.018163319	0.040178731	166.4386366	8.321931828	0.040178731	0.018163319	0.2	0.35
1998	31.46217	355.656	0.014686001	0.050585348	123.7036353	6.185181766	0.050585348	0.014686001	0.2	0.35
1999	35.2938	33.81202	0.014428253	0.041645661	103.6063045	5.180315223	0.041645661	0.014428253	0.2	0.35
2000	114.277	250.3251	0.017138573	0.035180334	119.9232216	5.996161082	0.035180334	0.017138573	0.2	0.35
2001	192.7073	293.7747	0.018307718	0.037456937	115.9012209	5.795061044	0.037456937	0.018307718	0.2	0.35
2002	44.44381	269.4851	0.013478347	0.039649519	113.4305349	5.671526744	0.039649519	0.013478347	0.2	0.35
2003	106.7079	411.6928	0.017501232	0.039875393	76.75977652	3.837988826	0.039875393	0.017501232	0.2	0.35
2004	87.83028	507.5868	0.01406431	0.040071866	99.06188187	4.953094093	0.040071866	0.01406431	0.2	0.35
2005	224.3407	108.3704	0.017005674	0.036403412	104.204714	5.210235702	0.036403412	0.017005674	0.2	0.35
2006	111.7935	69.62018	0.018102407	0.035319468	80.5723522	4.02861761	0.035319468	0.018102407	0.2	0.35
2007	242.488	157.6294	0.016077647	0.039473075	100.4376465	5.021882323	0.039473075	0.016077647	0.2	0.35
2008	20.98381	380.4426	0.0141	0.0436	101.957779	5.097888951	0.0436	0.0141	0.2	0.35
2009	113.5539	836.5922	0.0186	0.0385	164.6423021	8.232115104	0.0385	0.0186	0.2	0.35
2010	79.53799	1105.407	0.0136	0.0401	298.496874	14.9248437	0.0401	0.0136	0.2	0.35
2011	40.94383	607.0882	0.016	0.0424	377.759434	18.8879717	0.0424	0.016	0.2	0.35
2012	33.3968	813.0006	0.015085937	0.042655861	244.3978332	12.21989166	0.042655861	0.015085937	0.2	0.35
2013	28.08283	495.9772	0.014506188	0.042748631	295.4714503	14.77357252	0.042748631	0.014506188	0.2	0.35
2014	36.4934	140.2522	0.015672785	0.042058611	138.8776257	6.943881284	0.042058611	0.015672785	0.2	0.35
2015	31.34956	119.4181	0.016656	0.032924	-	-	0.032924	0.016656	0.2	0.35

Table 8: Summary of results from Catch Survey Analysis model (version 3.1.1) with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	80.2722	220.311	0.3325	10334
1994	43.0884	181.92	0.2228	8940
1995	60.42	153.848	0.2857	7951
1996	272.301	135.2385	0.3091	10210
1997	107.6735	251.645	0.7246	12118
1998	70.8668	146.6195	0.9909	8577
1999	214.369	68.1724	0.553	5845
2000	279.0155	131.8725	0.3999	9641
2001	295.8085	229.8035	0.2855	14200
2002	108.9655	331.0765	0.3345	14871
2003	160.235	269.3385	0.2247	13604
2004	114.1425	287.9455	0.3217	13388
2005	212.611	246.319	0.2994	12835
2006	224.542	281.8125	0.1873	14630
2007	805.49	369.7925	0.1021	27449
2008	65.1797	885.14	0.1302	39644
2009	809.4795	693.8625	0.1323	42756
2010	392.478	1,101.75	0.251	49742
2011	178.405	988.24	0.463	44725
2012	129.9125	603.8055	0.4666	27795
2013	96.7919	386.847	1.1169	18255
2014	145.371	133.908	0.8089	7915
2015	92.3872	104.369	0	4952

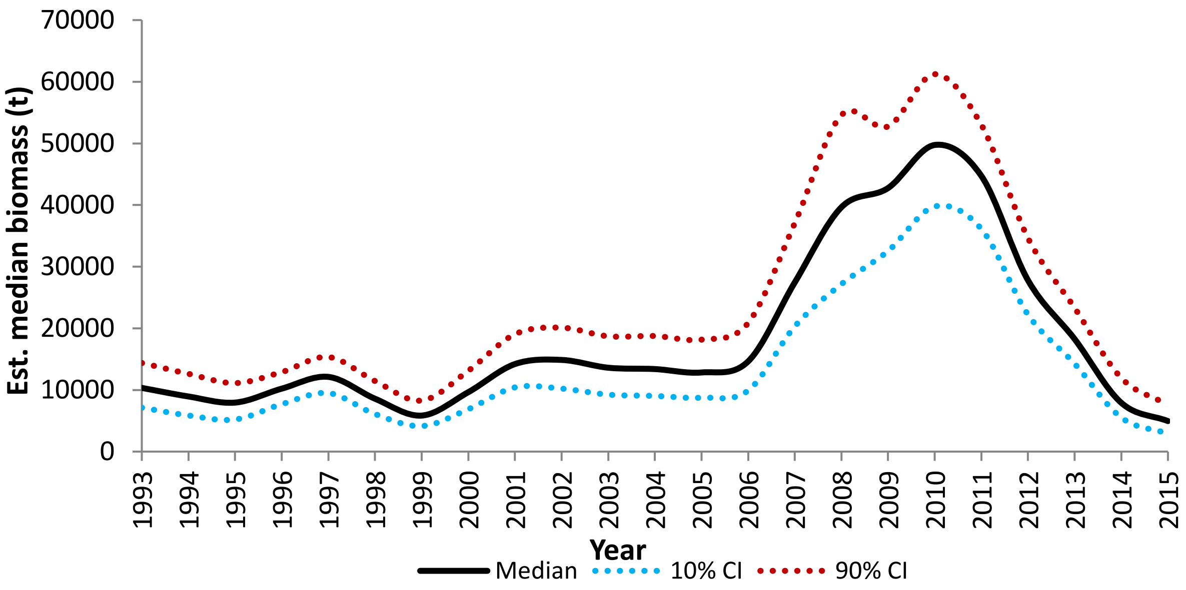

Figure 25: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5, 37E5 and 38E5) bootstrap results. (CSA Version 3.1.1)

Table 9: Summary of results from Catch Survey Analysis model (version 4.3) with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	91.2492	274.2235	0.27438	12443
1994	48.8045	227.6425	0.18604	10824
1995	69.2034	188.071	0.23852	9360
1996	303.4865	166.3025	0.27046	11717
1997	147.522	293.383	0.56525	14476
1998	95.8235	205.2165	0.638	11790
1999	185.199	130.346	0.47429	8104
2000	335.0245	160.765	0.3261	11411
2001	352.3785	293.3825	0.23252	17439
2002	124.1745	419.263	0.27591	18294
2003	190.8565	338.007	0.18395	16804
2004	138.019	360.048	0.26213	16377
2005	243.975	313.9035	0.24384	15586
2006	242.5835	358.3585	0.16849	17064
2007	862.54	416.165	0.0953	30283
2008	73.4866	950.95	0.12207	42516
2009	833.6965	743.105	0.12824	44187
2010	443.391	1,136.62	0.24467	51619
2011	220.537	1,014.33	0.43035	46547
2012	147.375	657.837	0.42632	30314
2013	104.4595	431.064	0.98536	19943
2014	142.864	163.672	0.73063	9126
2015	92.3843	120.9115	0	5531

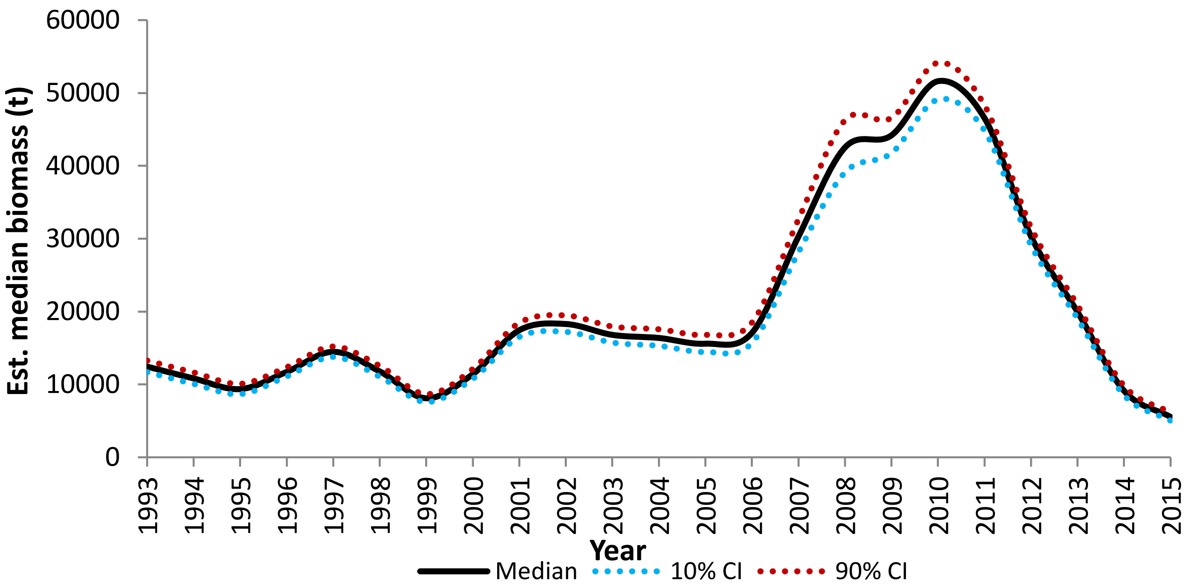

Figure 26: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5, 37E5 and 38E5) MCMC results (CSA Version 4.3).

Appendix 4.Revised Model 2 (Includes 38E5 & St. 7; Excludes St. BRI & 8): data input and outputs for CSA version 3.1.1 & version 4.3

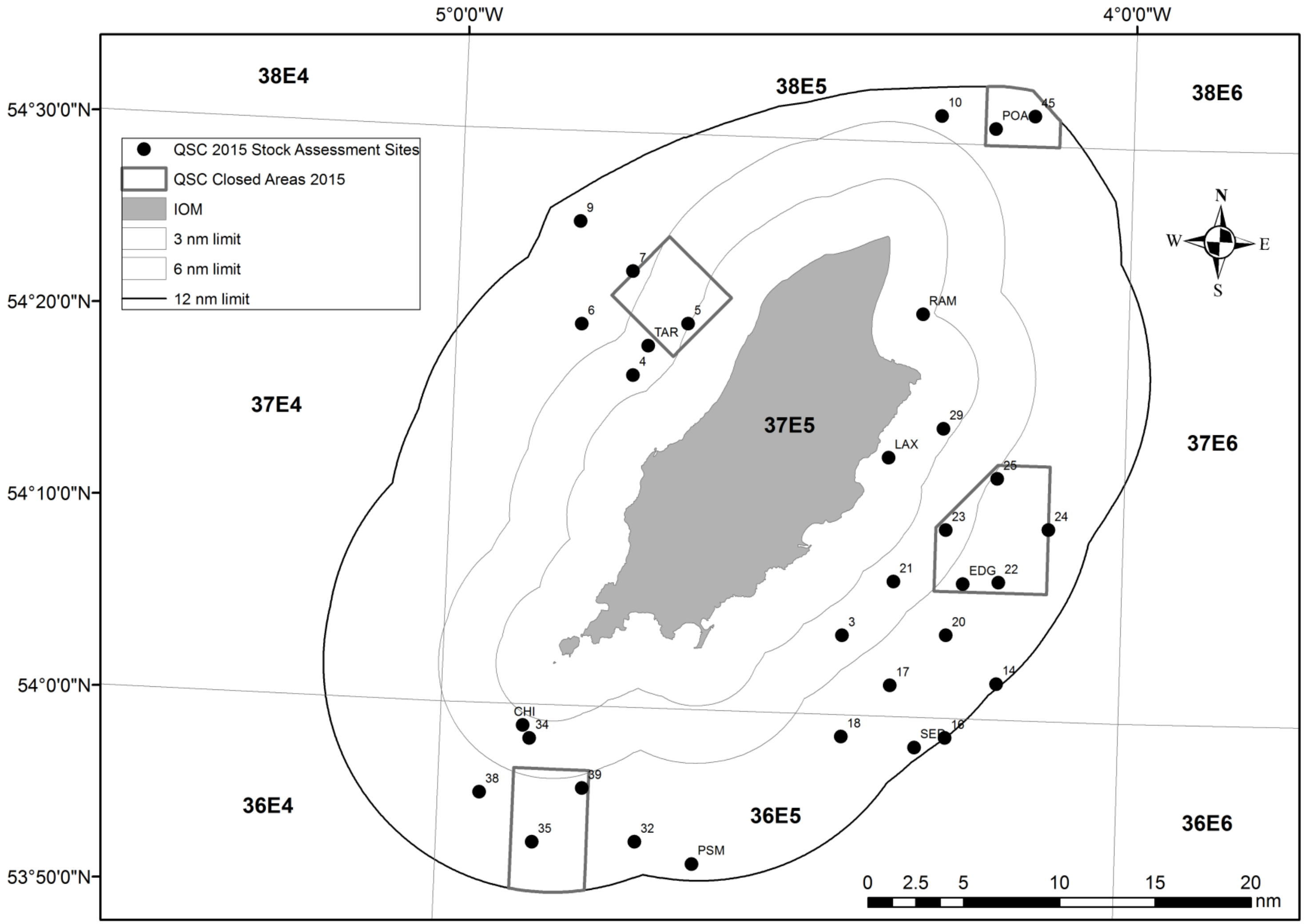

Figure 27: A map displaying only the actual survey stations within the Isle of Man territorial sea used in the revised version 2 of the 2015 queen scallop stock assessment model. For this stock assessment model the stock assessment unit covers the area of the three ICES rectangles 36E5, 37E5 and 38E5 (Stations POA, 10 and 45). Includes St. 7 & excludes St. BRI & 8.

Table 10: Input data for the revised version 2 of the 2015 queen scallop stock assessment model

	Survey				*Catch*				*Biological*	
	Survey Numbers		Weight per Individual		Catch Numbers		Weight per Individual		Natural Mortality	Recruit Selectivity
Survey Year	Recruits	Post-Recruits	Recruits	Post-Recruits	Landings	Discards	Landings	Discards		
1993	30.13425654	347.0402466	0.018731828	0.039115466	76.08161921	3.80408096	0.039115466	0.01873183	0.2	0.35
1994	15.86583449	174.5156615	0.018320125	0.043612203	40.62975081	2.03148754	0.043612203	0.01832013	0.2	0.35
1995	15.02050842	127.1489703	0.017112799	0.043411184	47.38438214	2.369219107	0.043411184	0.0171128	0.2	0.35
1996	46.91394182	77.46436025	0.01719857	0.03908781	96.60382917	4.830191459	0.03908781	0.01719857	0.2	0.35
1997	30.13695148	337.8036495	0.018163319	0.040178731	166.4386366	8.321931828	0.040178731	0.01816332	0.2	0.35
1998	31.46216705	355.6560054	0.014686001	0.050585348	123.7036353	6.185181766	0.050585348	0.014686	0.2	0.35
1999	35.29379961	33.81202304	0.014428253	0.041645661	103.6063045	5.180315223	0.041645661	0.01442825	0.2	0.35
2000	114.2770179	250.3250707	0.017138573	0.035180334	119.9232216	5.996161082	0.035180334	0.01713857	0.2	0.35
2001	192.7072587	293.774687	0.018307718	0.037456937	115.9012209	5.795061044	0.037456937	0.01830772	0.2	0.35
2002	44.44380737	269.4850984	0.013478347	0.039649519	113.4305349	5.671526744	0.039649519	0.01347835	0.2	0.35
2003	106.7079497	411.692814	0.017501232	0.039875393	76.75977652	3.837988826	0.039875393	0.01750123	0.2	0.35
2004	87.83028495	507.586832	0.01406431	0.040071866	99.06188187	4.953094093	0.040071866	0.01406431	0.2	0.35
2005	224.3407131	108.3704358	0.017005674	0.036403412	104.204714	5.210235702	0.036403412	0.01700567	0.2	0.35
2006	111.7935305	69.62017932	0.018102407	0.035319468	80.5723522	4.02861761	0.035319468	0.01810241	0.2	0.35
2007	242.4880336	157.6293945	0.016077647	0.039473075	100.4376465	5.021882323	0.039473075	0.01607765	0.2	0.35
2008	21.61892621	581.4203338	0.0141	0.0436	101.957779	5.097888951	0.0436	0.0141	0.2	0.35
2009	135.1149428	1282.488027	0.0186	0.0385	164.6423021	8.232115104	0.0385	0.0186	0.2	0.35
2010	102.6363772	1642.350555	0.0136	0.0401	298.496874	14.9248437	0.0401	0.0136	0.2	0.35
2011	42.4943261	877.5682037	0.016	0.0424	377.759434	18.8879717	0.0424	0.016	0.2	0.35
2012	38.03105498	1085.496636	0.015085937	0.042655861	244.3978332	12.21989166	0.042655861	0.01508594	0.2	0.35
2013	29.62900843	579.9250842	0.014506188	0.042748631	295.4714503	14.77357252	0.042748631	0.01450619	0.2	0.35
2014	40.69622256	146.3773637	0.015672785	0.042058611	138.8776257	6.943881284	0.042058611	0.015672785	0.2	0.35
2015	34.79939905	160.3243694	0.016656	0.032924	0	0	0.03292404	0.016656039	0.2	0.35

Table 11: Summary of results from Catch Survey Analysis model (version 3.1.1) with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	72.1126	227.2505	0.336	10248
1994	38.6775	179.718	0.2321	8696
1995	37.8232	146.941	0.3448	7117
1996	304.7635	108.549	0.3092	9650
1997	103.142	251.603	0.7534	12044
1998	65.2025	138.6935	1.1354	8034
1999	217.45	54.5293	0.5761	5418
2000	266.073	124.932	0.4236	9305
2001	292.337	214.1425	0.3004	13539
2002	101.8665	312.1225	0.3656	13679
2003	148.1235	242.293	0.248	12453
2004	103.217	257.554	0.3665	11986
2005	191.3575	210.9615	0.3493	11021
2006	212.7795	235.0725	0.2188	12602
2007	1,067.18	311.33	0.0867	29999
2008	59.7843	1,050.49	0.1114	47012
2009	842.0855	819.003	0.1172	48903
2010	434.6675	1,252.98	0.2254	56166
2011	139.1485	1,115.71	0.4228	49432
2012	117.3555	676.1335	0.4259	30877
2013	81.6116	433.4945	1.0222	19778
2014	143.8085	154.9145	0.7359	8906
2015	92.5326	119.6895	-	5491

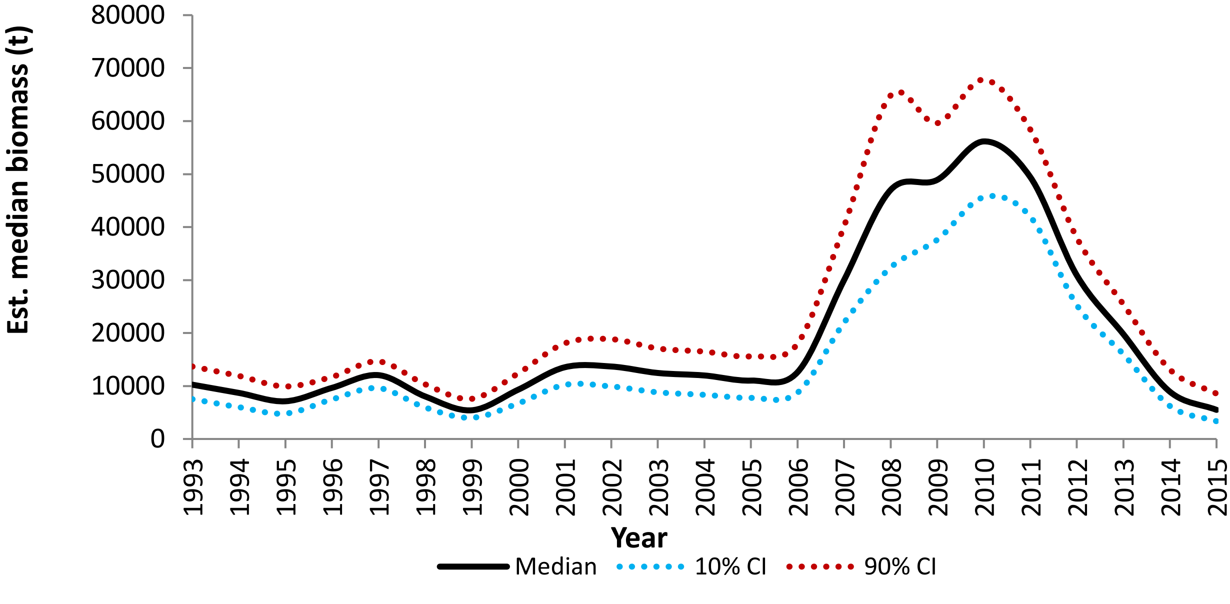

Figure 28: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5, 37E5 and 38E5) bootstrap results. (CSA Version 3.1.1)

Table 12: Summary of results from Catch Survey Analysis model with median estimates (M = 0.25; s = 0.35 and percentile range = 10% - 50% - 90%) (CSA Version 4.3)

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	80.8229	251.447	0.30624	11351
1994	43.1701	200.3985	0.2137	9533
1995	44.0528	161.0485	0.30939	7747
1996	314.743	123.45	0.29235	10255
1997	142.4855	268.25	0.62145	13353
1998	89.4661	180.637	0.74278	10454
1999	179.131	105.219	0.54156	6979
2000	313.178	135.532	0.36708	10149
2001	326.5545	254.6825	0.26193	15516
2002	112.2375	366.181	0.31931	16043
2003	172.4115	285.0785	0.21564	14392
2004	122.25	301.89	0.31521	13822
2005	214.2905	253.6915	0.29887	12882
2006	216.477	284.262	0.20575	13975
2007	1,055.23	334.2425	0.08738	30179
2008	64.0099	1,041.61	0.11247	46334
2009	887.127	809.4595	0.11879	47726
2010	471.595	1,233.87	0.2244	55932
2011	169.6805	1,118.13	0.40873	50150
2012	131.069	701.3975	0.41035	31900
2013	88.8323	452.5595	0.97072	20630
2014	143.217	167.8875	0.71378	9310
2015	87.3571	124.8815	-	5573

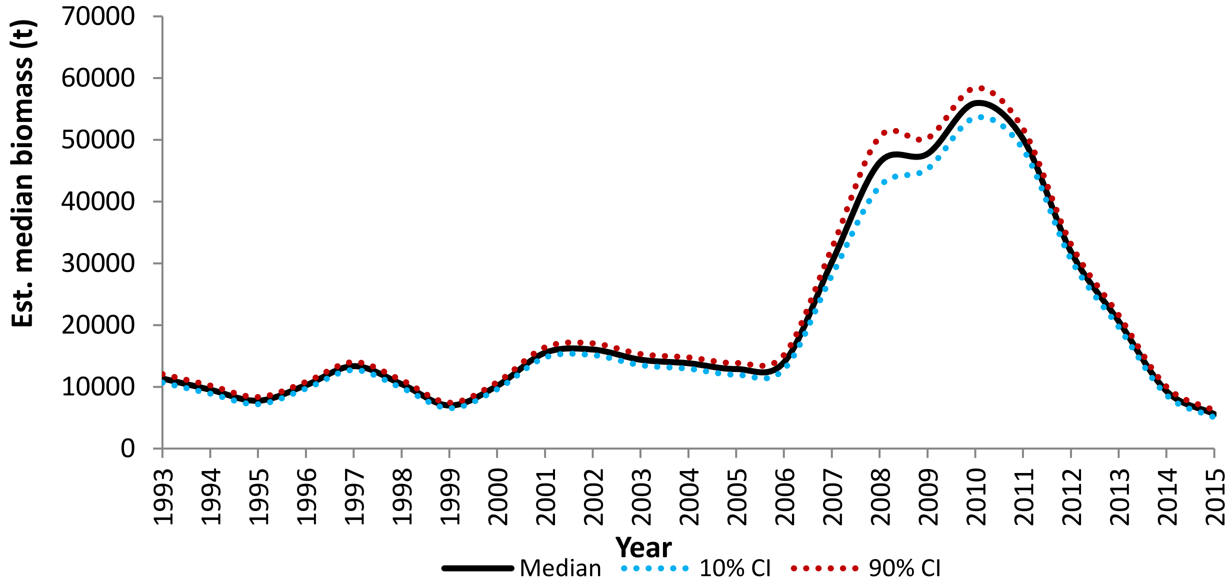

Figure 29: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5, 37E5 and 38E5) MCMC results. (CSA Version 4.3)