The Isle of Man *Aequipecten opercularis* fishery stock assessment 2016

Final Report

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Preface

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

Version Control: Final Report (V2) 30/07/2016

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. Most Manx vessels now fish for queen scallops with otter trawls, while UK vessels use both otter trawls and toothless dredges. Traditionally 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, under which recruitment is considered to be impaired, the MSC certification for this fishery was suspended on May 19th 2014 and remains in suspension at present.

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 sharply declined in 2014 and 2015. Across ICES rectangles 36E5 and 37E5, in 2015, approximately 81% of landings were taken by dredgers and 19% by otter trawlers (in the year from January to December 2015). By comparison, within the territorial sea approximately 16% of landings were taken by dredges and 84% by otter trawlers (in the year 2015 from January to December).

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 indicates that the biomass of post-recruits declined between 2010 and 2016, while recruit biomass declined sharply between 2009 and 2011 and has been variable between 2012 and 2016. Total biomass within the territorial sea is estimated to have declined by over 21000t between 2010 and 2016 with the median estimated biomass for 2016 of 4776t is now back within the bounds of historic averages. Landings from the territorial sea were higher in 2016 (1240t) than in 2015 (1000t) despite a continued decline in estimated stock biomass.

The MSC process requires that a minimum and maximum biomass threshold is calculated for the stock (minimum biomass threshold calculated as approximately 13000 t for ICES rectangles 36E5 and 37E5). In terms of setting an appropriate harvest rate, analysis of the historic data indicates that when the stock is above the minimum biomass threshold removing more than 30% of queen scallop biomass increases the risk that the stock will be depleted (Murray, 2013). When biomass is lower than this minimum threshold recruitment may be impaired and it is recommended that fishing should severely reduce or cease, in order to promote the earliest possible return of the stock to levels above the minimum biomass threshold. Should fishing occur for socio-economic purposes at biomass levels

below the recommended minimum biomass threshold it is recommended that a very precautionary harvest strategy is adopted (e.g. 20% or lower).

Given recent biomass depletion, a scientifically advised TAC was not provided for the 2015/16 season for ICES Rectangles 36E5 and 37E5. Contrary to scientific advice, a TAC of 1240t was set by the Queenie Management Board for the territorial sea. This was a socio-economic measure to ensure short-term job security in the scallop processing and catching sectors.

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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. Most Manx vessels now fish for queen scallops with otter trawls, while UK vessels use both otter trawls and toothless dredges. The fishery within the territorial sea is governed by several management measures. For the 2015/2016 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 2016)
- Weekend ban
- Daily curfew (06:00 – 18:00)
- Weekly catch limits (maximum of 4200 kg for trawl and 10500 kg for dredge)
- Minimum landing size (55 mm)
- Limited TAC (1240 t)

These management measures were covered by the Fisheries Act 2012 and through restrictive licencing conditions.

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 Isle or Man's queen scallop 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 results 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 vessels licenced to fish for queen scallops within the territorial sea from 138 (2014) to 49 (2015), although at this time two of these licences are currently inactive, addressing the issue of unrestricted latent effort within the fishery. Of the 49 vessels licenced to fish for queen scallops during the 2015/16 fishing season only 35 prosecuted the fishery.

Outside of the territorial sea although a minimum landing size of 40 mm is enforced the fishery is subject to very few additional management measures. However, in May 2016 industry has for the first time implemented a voluntary closure for ICES areas VIa and VIIa to protect the fishery during one of its spawning periods.

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. The MSC certification remains in suspension at present.

1.3 Recent increases in fishing effort and measures to address management needs

An increase in the demand for queen scallops in 2010 prompted industry discussions about the management of the fishery. In July 2013 a meeting of the UK 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 predicted reduction in biomass based on the 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 in December 2014, were continued into 2015.

In March 2015 Marine Scotland began coordinating the project, and the first meeting with the scallop fishing industry was held in Edinburgh. A joint industry and fisheries administrations Working Group was then established to determine which management measures should be adopted and how this could be achieved. Changes to the minimum landing size and seasonal closures remained the primary short-term objectives; although a range of potential longer-term management measures were also considered.

This process continued during 2015, with meetings in May, August and October, during which a public consultation document was developed by the working group. The document was finally agreed in early 2016 but was not released due to a request from the Welsh Government to avoid potential conflict with their consultation on scallop management in Cardigan Bay. Subsequent delays have also occurred and the consultation is now likely for release in June or July 2016. A Business Regulatory Impact Assessment for the proposed measures will also accompany the consultation document.

The consultation will seek views on;

- Changes to minimum landing size.
- Statutory fishery closure for spawning purposes.
- Entry restrictions for the fishery.
- Potential future management options for the fishery including; input and output controls, spatial management and technical measures.

In the meantime, a voluntary closure of the queen scallop fishery during May 2016 was agreed with industry in Areas VIa and VIIa, which appears to have been observed.

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 (2012a, 2012b), Murray (2013) and Bloor *et al.,* (2014, 2015). CSA has been advocated as a valuable method to support management advice where age data is not available (Mesnil, 2003). 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. 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).

2. Methods

2.1 Scallop surveys and abundance index

Spring surveys of the Isle of Man's scallop populations have been undertaken annually in spring since 1992 (Beukers-Stewart *et al*., 2003). The original surveys (1992 – 2006) conducted by Port Erin Marine Laboratory sampled scallops across a range of 11 historical survey stations, although not all stations were sampled every 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 1). The recent surveys (2007 – 2016) conducted by Bangor University continued sampling of these historical stations and increased sampling effort from 2012 onwards, including additional fixed survey stations across the extent of the queen scallop stock within the territorial sea (Figure 1).

Stations that have been sampled over at least two years (3, 4, 5, 9, 10, 14, 17, 20, 21, 22, 23, 24, 25, 32, 35, 36, 38, 39 and 45), in addition to the standard historical queen scallop survey stations (CHI, EDG, LAX, POA, PSM, RAM, SED and TAR), were included in the current stock assessment (Figure 2). For the first time the model for 2016 was run at the smaller spatial scale of the territorial sea in comparison to the larger spatial scale of ICES Rectangles 36E5 and 37E5 that has previously been used. By using landings and survey data exclusive to the Isle of Man territorial sea, this has also enabled survey data from stations in ICES statistical rectangle 38E5 (and landings from this area) to be incorporated into the model for the first time. However, it is important to note that this area was not surveyed before 2008 and only a single station has been sampled in most years since then. Since 2014 at least three stations (POA, 10, 45) have been sampled, with five stations surveyed in 2015 and 2016 (POA, 10, 11, 13, 45) (Appendix 1). In addition, data for historical landings (e.g 1992 – 2006) were compiled from multiple sources and are only attributable to the level of ICES Rectangle. For years that VMS data are available (2007 - 2013) landings data attributable to ICES Rectangle can be combined with spatial data from VMS to enable a finer scale spatial resolution (e.g. inside or outside the territorial sea). Landings data from the most recent years in the model (2013 – 2016) has been collated at a finer resolution and so can be accurately resolved to the territorial sea. As such the partitioning of landings originating from inside and outside the territorial sea is more robust for recent years and less robust the further back the data set originates (Figure 4).

All stations were surveyed using the protocol described by Hinz *et al*. (2009) and Murray *et al*. (2009). The stock assessment survey was undertaken using the RV Prince Madog from 25th April – 8th May 2016.

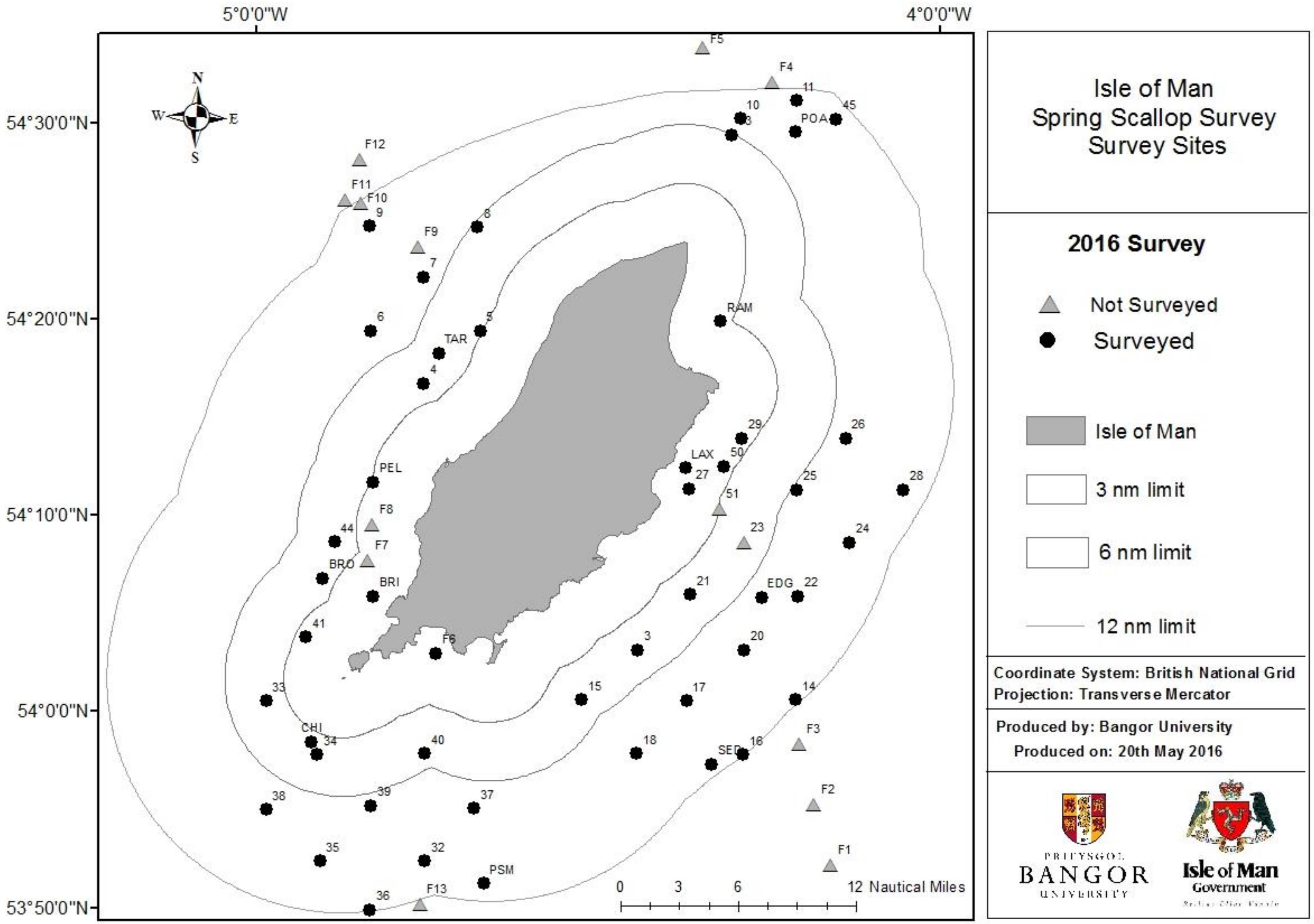

Figure 1: Map showing all stations surveyed during the 2016 stock abundance survey (solid black circles) and in previous annual stock abundance surveys (solid grey triangles). Stations prefixed with an 'F' are stations selected by local fishing industry representatives. Named stations were first surveyed from 1992 whilst numbered stations were first surveyed from 2012. The full set of sample sites was not achieved in 2016 due to adverse weather conditions which limited the number of sampling days available during the survey period.

The geometric mean of queen scallop density was calculated across survey stations and was used to derive the abundance indices. This was precautionary and necessary to obtain meaningful stock assessment results. A failure to use the geometric mean which down-weights isolated high-density patches of scallops would increase the risk of over-estimating population size (Hutchings, 1996) and would provide a misleading over-optimistic estimate of scallop abundance.

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, particularly when compared to fish species (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 the potential for 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 physiological stress and resulting in 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 (e.g. if 21% of landings are discarded as they under MLS and 19% of those are estimated to suffer mortality, this then equates to a discard mortality of around 5% of the original landed weight). However, *in situ* mortality resulting from interaction with fishing gear is unknown.

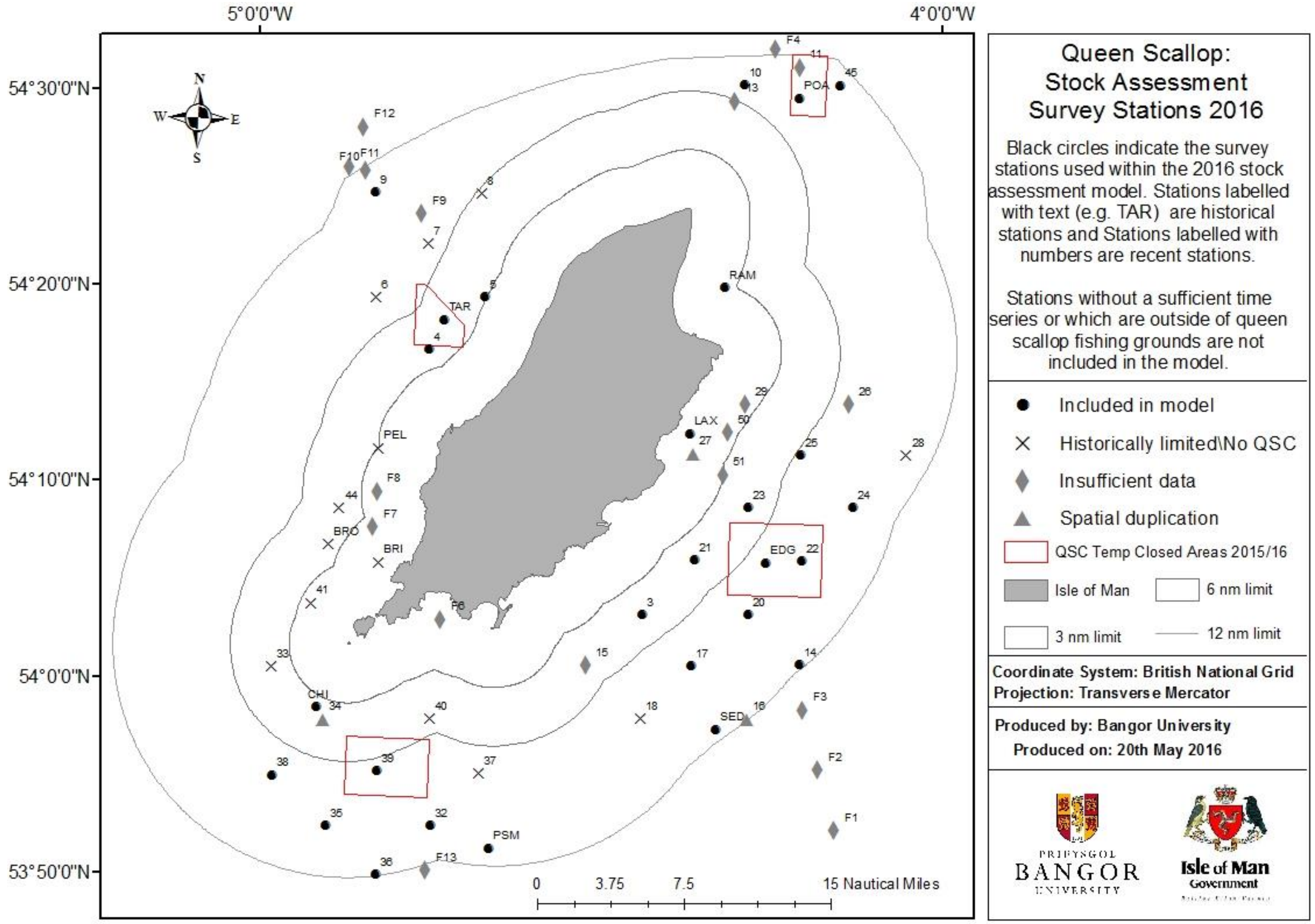

Figure 2: A map displaying the actual survey stations within the Isle of Man territorial sea used in the 2016 queen scallop stock assessment model and the primary reason why the remaining stations were excluded from the analysis. Named stations were first sampled from 1992 onwards, whilst numbered stations were first sampled from 2012 onwards. For 2016, the stock assessment presented in the main section of this report was undertaken for the Isle of Man territorial sea. Categories: Included in model – Stations used to calculate the abundance indices for input into the current model; Historically limited\No QSC- Stations that have consistently recorded no (or very minimal) queen scallop density during the survey; Insufficient data – Stations that have been surveyed for 2 years or less and therefore do not have a long enough time series of data to allow inclusion in the model; Spatial duplication – New stations that have been created in a grid but that overlap with historic stations and so have been excluded to avoid duplication.

2.2 Stock assessment

The stock assessment was implemented using CSA v3.1.1 (NOAA, 2008) [for more details on these versions see Section 4.3.1; 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 previously has been defined as the area covered by ICES statistical rectangles 36E5 and 37E5 (Figure 3). Although this area includes the majority of queen scallop fishing grounds within the territorial sea it causes a spatial mismatch between the main data sets that input into the stock assessment model. This is because the survey area used to create the abundance index is at the spatial extent of the Isle of Man territorial sea, while the area from which landings data are collated is the wider spatial extent of ICES Rectangles 36E5 and 37E5 (Figure 3). Due to the limited spatial resolution available for older landings data sets ICES rectangles 36E5 and 37E5 have been 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.

A wide range of management regulations recently have been implemented within the Isle of Man's fisheries. There remain minimal management measures in place for queen scallop fisheries within the wider Irish Sea. VMS and Logbook data analysis has indicated that generally around 50% of the landings from these ICES rectangles have come from within the territorial sea and 50% from outside. However, in more recent years, due to restrictive management measures that have been put in place for the queen scallop fishery within the territorial sea, there has been a significant shift in these proportions. For 2014 and 2015 it was estimated that only around 15% of the landings from these two ICES rectangles came from inside the territorial sea and 85% from outside. This shift means that the landings data used to input into the model are becoming less applicable to the current situation and highlights the need to move towards realigning the spatial extents of the datasets that input into the model to the spatial extent of the management unit (territorial sea) rather than the extent of the wider stock unit (Irish Sea or ICES rectangles 36, 37 and 38 E5). Whilst accurate data for landings from the territorial sea are available from 2012 onwards, for all years' prior to 2012 the data is only resolved to ICES statistical rectangle. In order to apportion part of the older landings data to the territorial sea an assumption that 50% of queen scallop landings from ICES rectangles 36E5, 37E5 and 38E5 have come from inside the territorial sea and 50% from outside in order to approximate landings from the territorial sea during these years.

Therefore, although the data for recent years has been accurately collated at the level of the territorial sea, confidence in historical landings data resolved from the level of ICES Rectangle to territorial sea is lower (Figure 4). This will build in a level of uncertainty and error into the historic predictions of biomass that will be resolved as the time series of data increases and the older data can be incrementally discarded from inclusion in the stock assessment model.

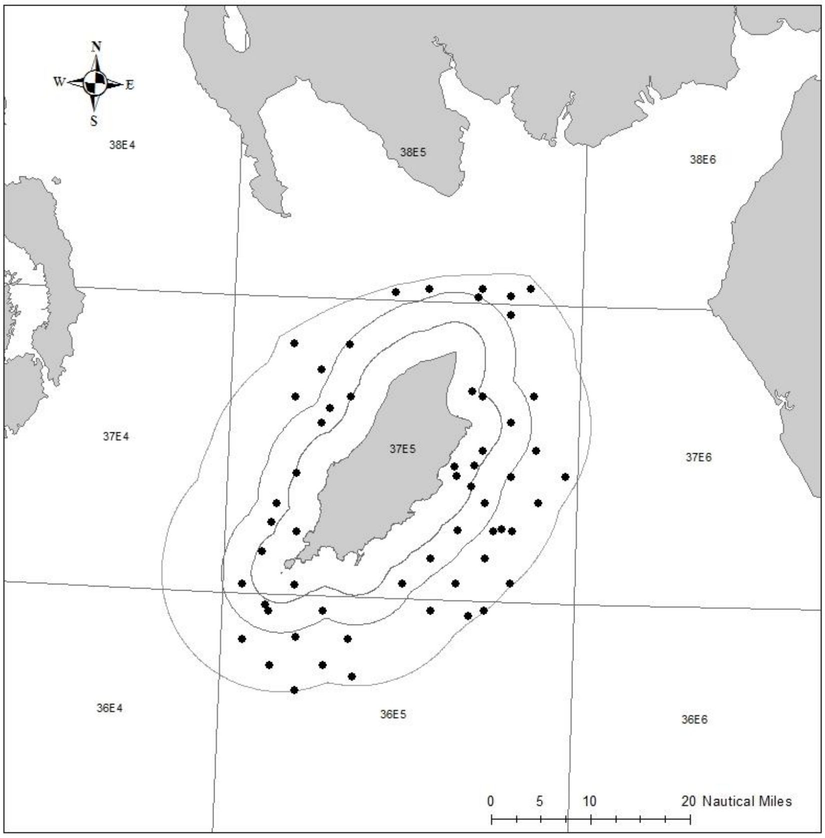

Figure 3: A map indicating the different spatial extents of the two main data sets that have previously been input into the stock assessment model. The abundance index from the territorial sea is at the spatial extent of the Isle of Man territorial sea whilst landings data are from ICES rectangles 36 and 37E5. The management unit is also at the spatial extent of the territorial sea.

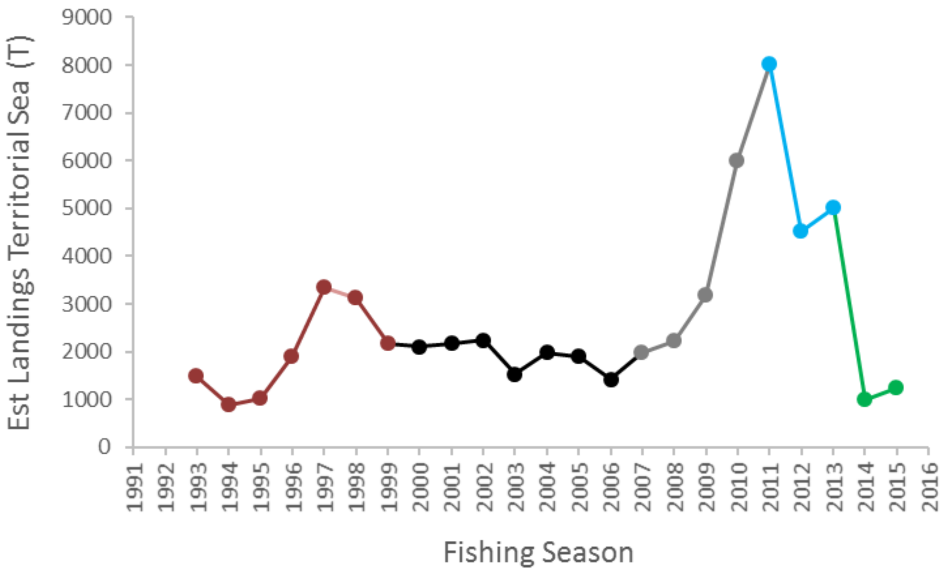

Figure 4: A graph illustrating the differences in confidence in the landings data obtained from different time periods. For the most recent years' data is reported spatially on a tow by tow basis as well as at a daily level. Green = Tow by tow spatial data within TS plus logbook and VMS data; Blue = DEFA monitored landings within TS and logbook and VMS data; Grey = landings from logbook and VMS data; Black = logbook and VMS data; Red = logbook data only at ICES rectangles level.

Abundance indices were derived from survey data from 1993 to 2016. 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*:

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

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:

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

and

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

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:

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

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. Research found almost no landings <55 mm for either dredgers or trawlers (Nall, 2011). Allison (1993) fitted Von Bertalanffy Growth Functions (VBGF) to length at age data of queen scallops from around the Isle of Man. Mean growth rate expressed as VBGF parameters were $L_\infty = 75.91$, k = 0.59 and $t_0 = -0.88$. This equates to approximately 30 mm growth for a scallop of 27.5 mm during 1 year. Therefore, recruits were considered to be queen scallops 25 to 54 mm length. However, the smallest size of scallops caught were 25 mm and these were rare; therefore, the recruitment index was in effect scallops between 30mm and 55mm. Allison (1993) used six different methods to estimate natural mortality, *M*, all yielding different results ranging from 0.037 to 1.88 but identified values of 0.2 to 0.5 as most appropriate. The effects of using values of *M* between 0.2 and 0.4 were examined in an earlier report (Murray and Kaiser, 2012a) and repeated in Appendix 10. Based on the earlier work of Murray and Kaiser (2012a) 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, 2005). 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 2015 the QMB met to discuss the scientific advice based on the biology and sustainability of the stock that recommended no fishing (Bloor *et al.,* 2015). Considering the socio-economic impacts of such a closure a limited economic TAC of 1240t 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 & 2015 meant that large areas of the territorial sea contained low densities of queen scallops. For the 2015/2016 fishing season four areas that had exhibited sufficiently high abundances in the April 2015 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. There is also evidence from within areas protected from towed bottom-fishing gear that adult scallops (*Pecten maximus*) had heavier adductor muscle tissue and gonads that were 19% - 24% heavier than those of scallops in fished areas potentially as a result of lower stress levels from reduced contact with fishing gear (Kaiser *et al*., 2007). 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 5).

As the main purpose of the closed areas was to promote successful spawning and spat delivery to areas around the entire Island, it will be difficult to separate any direct impacts from the closures of these areas on the recruitment success of the stock as a whole.

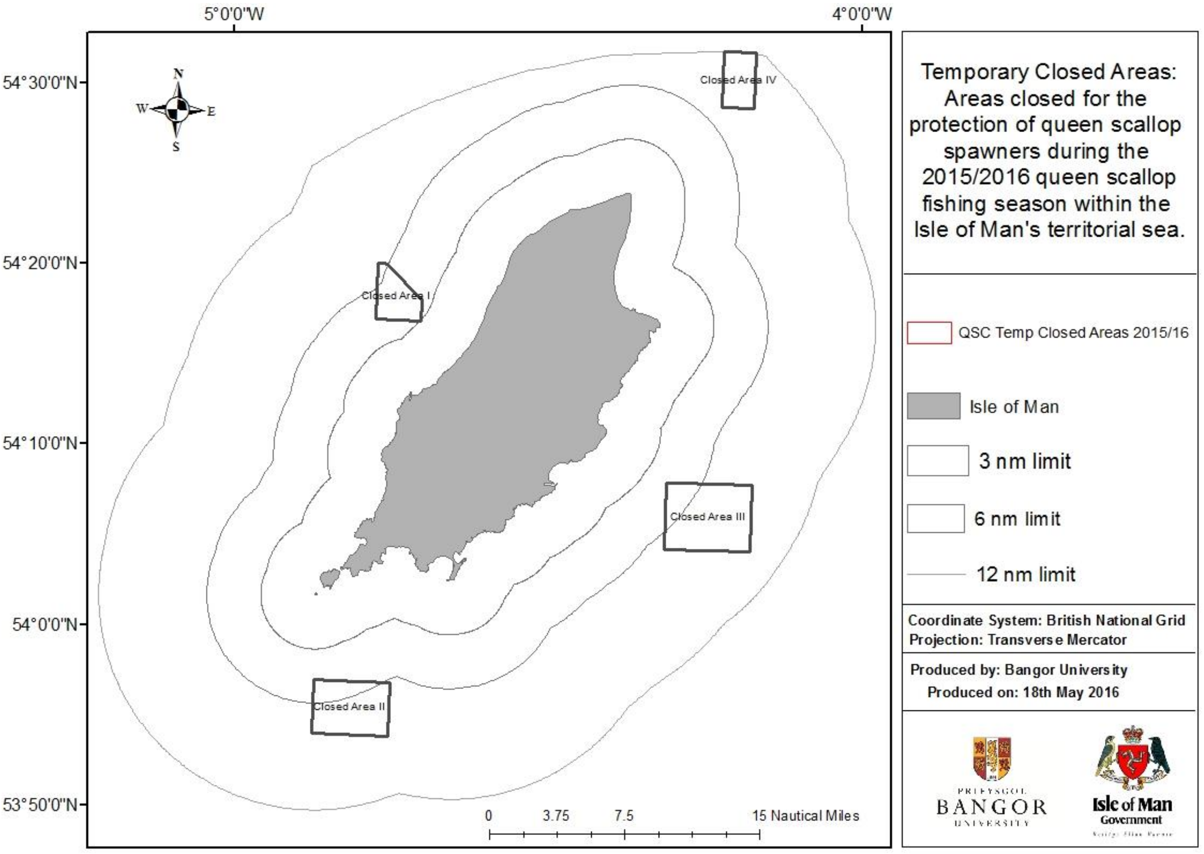

Figure 5: Four temporary queen scallop closed areas that were put in place for the 2015/2016 fishing season. Of these closed areas, Area I & IV remained in place for the duration of the 2015/2016 king scallop fishing season as well.

3. Results

3.1 Abundance

3.1.1 Whole Stock

The abundance index shows a declining trend in the mean abundance of recruits from 2009 to 2016 with slight increases observed in both 2012 and 2014 (Figure 6). From 2006 to 2010 there were year on year increases in the mean abundance of post-recruits, reaching the highest levels on record in 2010. However, the mean abundance of post-recruits has shown a declining trend since 2010, recovering to a level similar to that recorded prior to 2007 (Figure 6).

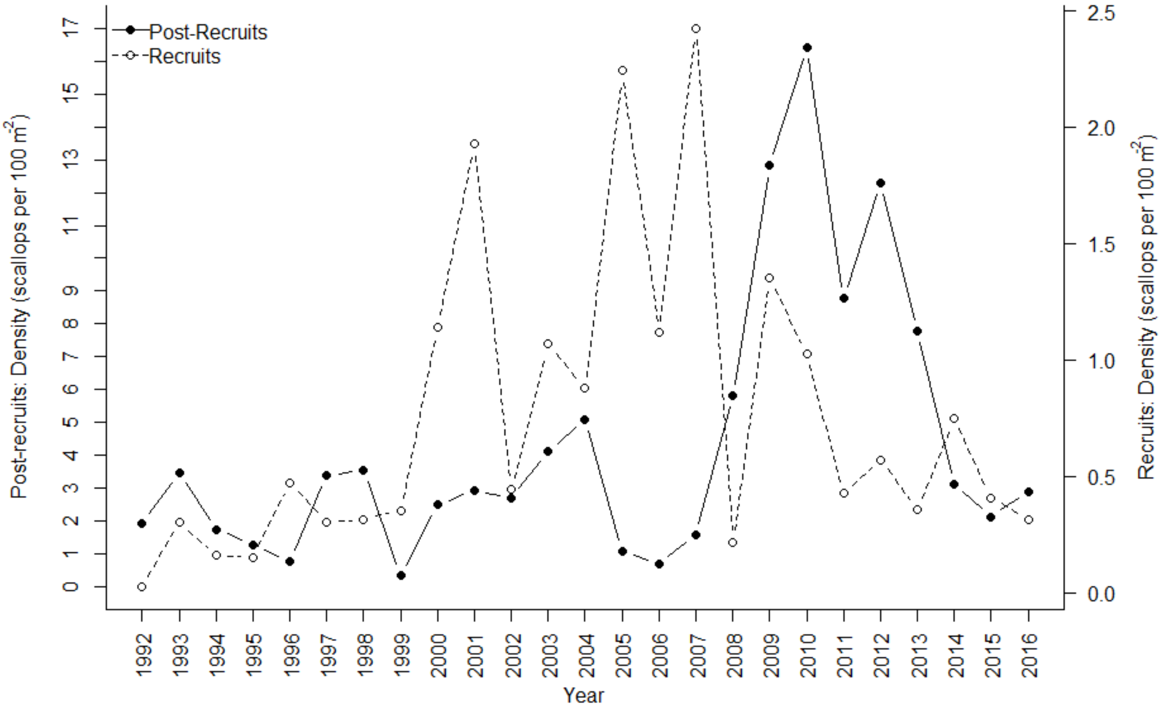

Figure 6: Abundance indices (based on geometric mean) for recruits and post-recruits used in the catch survey analysis model. This is calculated using data from only the stations used in the 2016 stock assessment model. Zero data values have been treated as 0.01 in order to calculate the geometric mean.

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 7 and Figure 8). In addition, due to the aggregating nature of queen scallops some areas of relatively high densities are evident within each of these fishing grounds. During the 2015/16 fishing season the highest density area was found within the fishing ground at Targets on the west coast, where 65% of landings were removed. The queen scallops within this area were generally large post-recruits of a similar size class (60– 70 mm).

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 8 for both 2015 and 2016. In 2016 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 8). Variation in the average density of queen scallops (of all sizes caught) per 100 m^2 varies temporally as can be seen in Figure 8 where the survey densities from 2009 and 2016 are compared. This graph indicates a large decrease in scallop density since 2009 at historical stations on the south and east of the Island, which had experienced a large recruitment event.

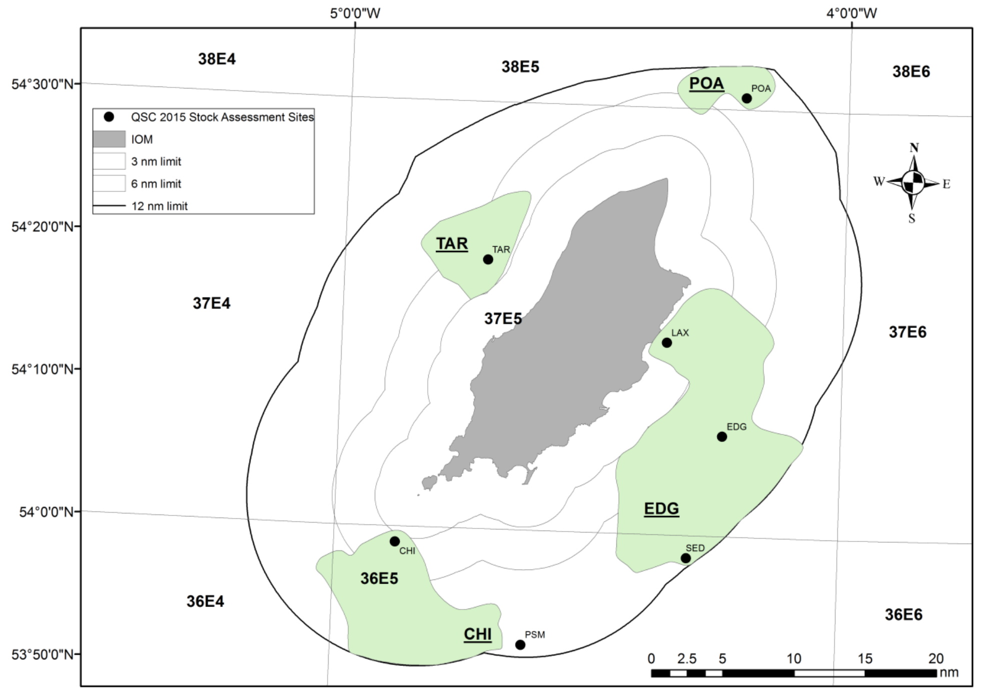

Figure 7: Map showing the approximate locations of the four main queen scallop fishing grounds (names underlined and in bold for clarity) within the territorial sea. The four main fishing grounds are known as EDG (East Douglas), CHI (Chickens), TAR (Targets) and POA (Point of Ayre). The historical stations within these sites are also labelled on the map.

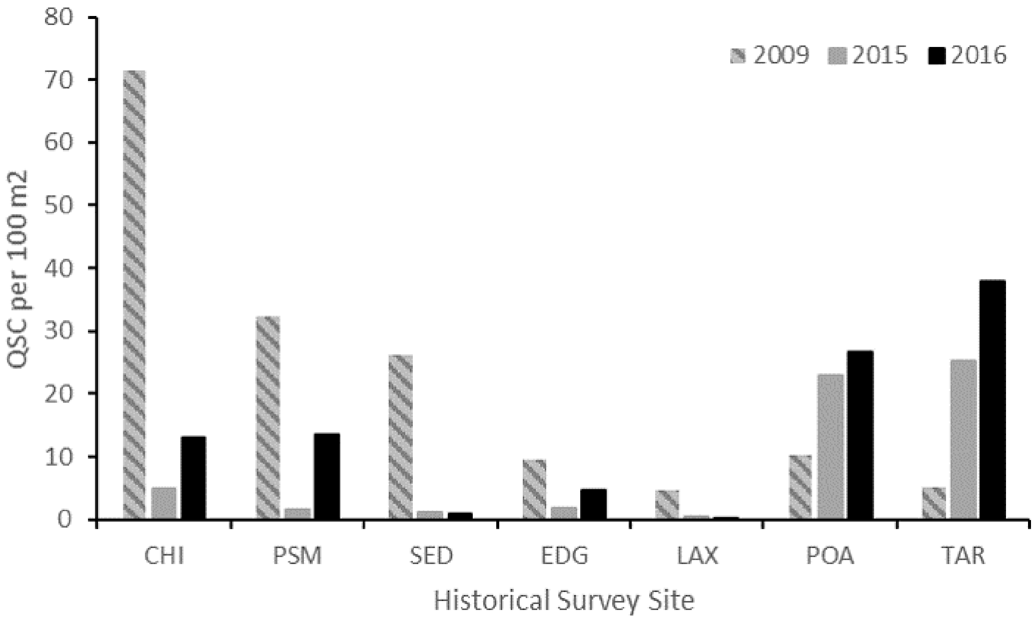

Figure 8: A comparison of the average density of queen scallops (number of scallops per 100 m^2) in queen scallop dredges from historical survey stations during the 2009 (grey patterned), 2015 (grey solid) and 2016 (black solid) stock assessment survey.

In addition, the proportion of recruits and post-recruits at each station also varies around the Island. Whilst some sites (e.g. TAR, 39) were composed entirely of post-recruits (over 55 mm) other stations (e.g 36, 21) were composed of over 60% recruits (25 – 54 mm) and less than 40% less post-recruits (over 55 mm).

3.2 Landings and fishing effort

Queen scallop landings from 36E5 and 37E5 totalled 8033t in 2015 (i.e. from January to December 2015), with an additional 58t caught in 38E5 (in the year 2015 from January to December). Of the total taken across the two rectangles (36E5 and 37E5), 6483t was caught by dredgers, 1550t by otter trawlers. Landings taken from 36E5 and 37E5 by Manx trawlers represented 14% and UK trawlers represented 5% of total landings in 2015. UK dredgers represented 76% and Manx dredgers represented 5% of total landings in 2015 (i.e. from January to December 2015). Landings of queen scallops from within the territorial sea were approximately 1240t in 2015 (Figure 11); this represents only 15% of total landings from 36E5 and 37E5 (in the year 2015 from January to December). The proportion of landings from 36E5 and 37E5 that originated from within and outside the territorial sea has changed substantially since 2014 as a result of changes to the management of the queen scallop fishery within the Isle of Man's territorial sea.

Landings from within the territorial sea have also changed substantially in respect of gear type since 2013 as a result of changes in management. 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 with no landings reported from dredges prior to the closure of the fishery on 2nd October 2014. In 2015 a proportion of the overall TAC (200t) was allocated to the dredge fishery which opened on 2nd October and closed on 14th October 2015. Entry into the dredge fishery was open to any vessel licenced to fish for queen scallops within the territorial sea and a total of 12 unique vessels took part landing approximately 16% of total landings from the territorial sea. In contrast 31 unique vessels prosecuted the trawl fishery in 2015 landing approximately 84% of total landings from the territorial sea.

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 substantially decreased again, for both Manx and UK vessels, in 2014. In 2015 this decline continued for Manx vessels whilst days at sea increased for UK vessels (both situations occurring with a small corresponding increase in landings) (Figure 10). For Manx vessels the majority of landings originate within the Isle of Man's territorial sea and this increase in landings with a decrease in days at sea can be explained by the isolated high density fishery that occurred off the west coast of the Island. A high density bed of large (60 – 70 mm) queen scallops had been identified in the 2015 annual Spring Scallop Survey at Station 5 situated within a closed area during the 2014/2015 fishing season and which was subsequently opened during the 2015/2016 fishing season to allow the fishery to target this area. The density and large size of queen scallops from within this area created a very efficient fishery with above average product prices. For UK vessels the proportion of landings coming from inside and outside the territorial sea is more varied. As seen in Figure 10, the majority of UK landings are from dredge rather than trawl vessels, whilst the majority of these trawl landings will originate within the territorial sea and for these vessels the same pattern is evident as for Manx vessels with a slight reduction in the number of days at sea and a small corresponding increase in landings. Due to the limited quota in place for dredge fishing within the territorial sea the majority of dredge landings originate from outside the territorial sea. For UK dredge vessels the pattern shows an increase in both landings and days at sea, with the larger increase corresponding to days at sea.

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, 2012a) 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%).

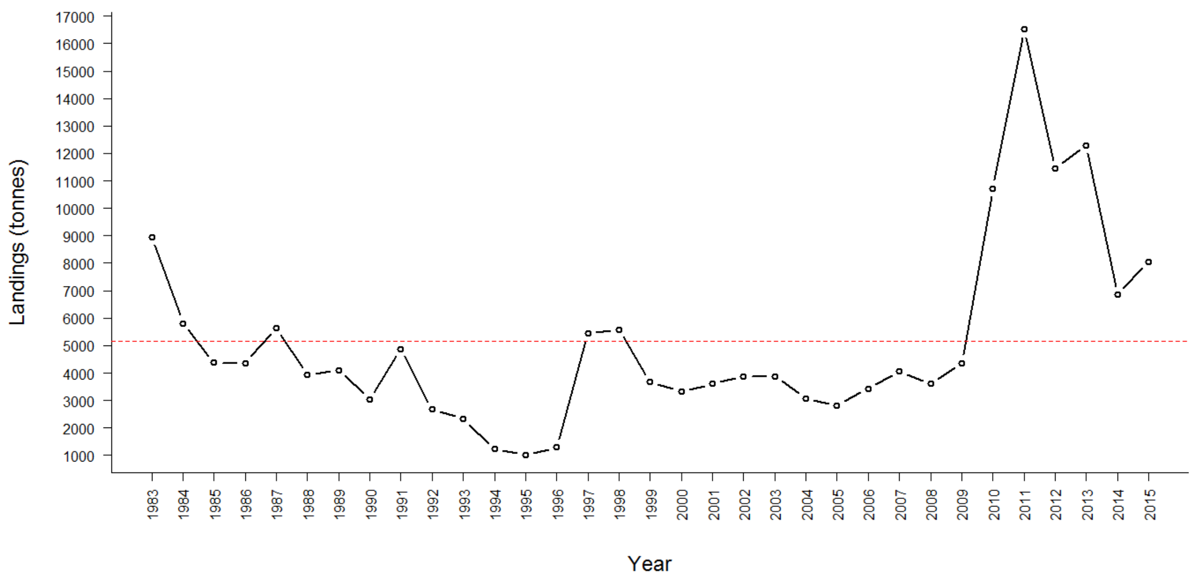

Figure 9: Landings (live weight) of queen scallops to the UK and Isle of Man. For comparison, the long-term average landings (1983 – 2016) of 5158t is marked on the graph by a dotted red line. Landings are referenced to ICES statistical rectangles 36E5 and 37E5 (as a proxy for territorial sea landings) 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 (i.e. from January to December for each year). Data source: Isle of Man Government, DEFA and IFISH.

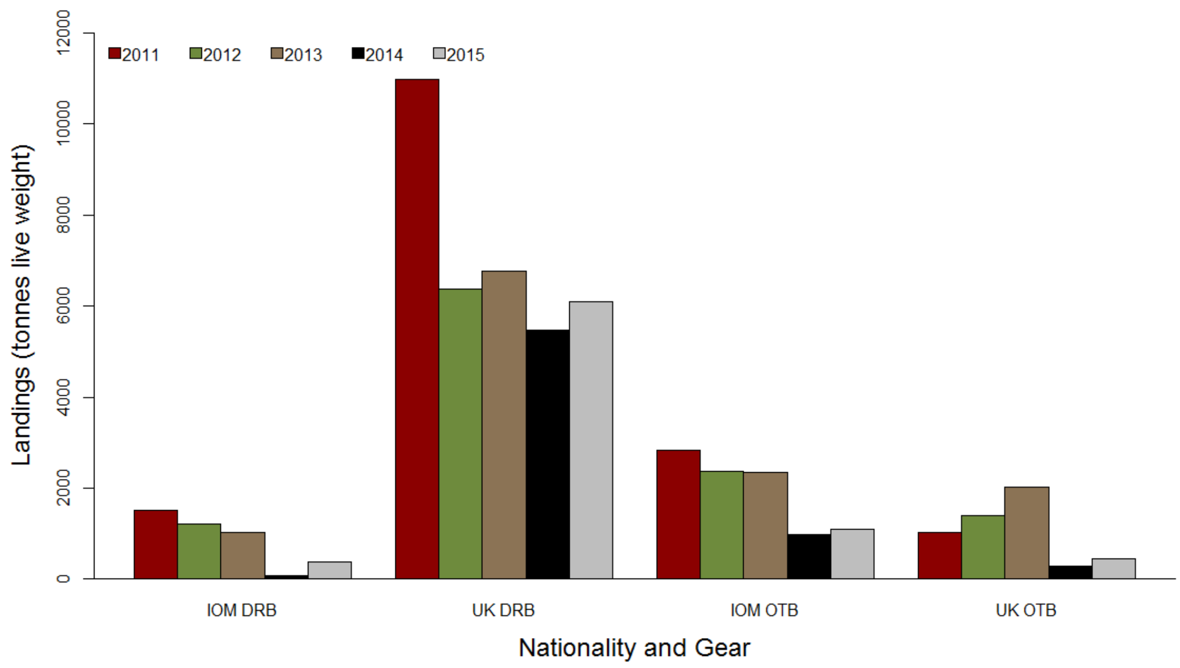

Figure 10: Landings from 36E5 and 37E5 by UK and Isle of Man (IOM) dredgers (DRB) and queen scallop trawlers (OTB). Data are derived from the iFISH database and DEFA and are for calendar years (i.e. from January to December for each year), rather than fishing years.

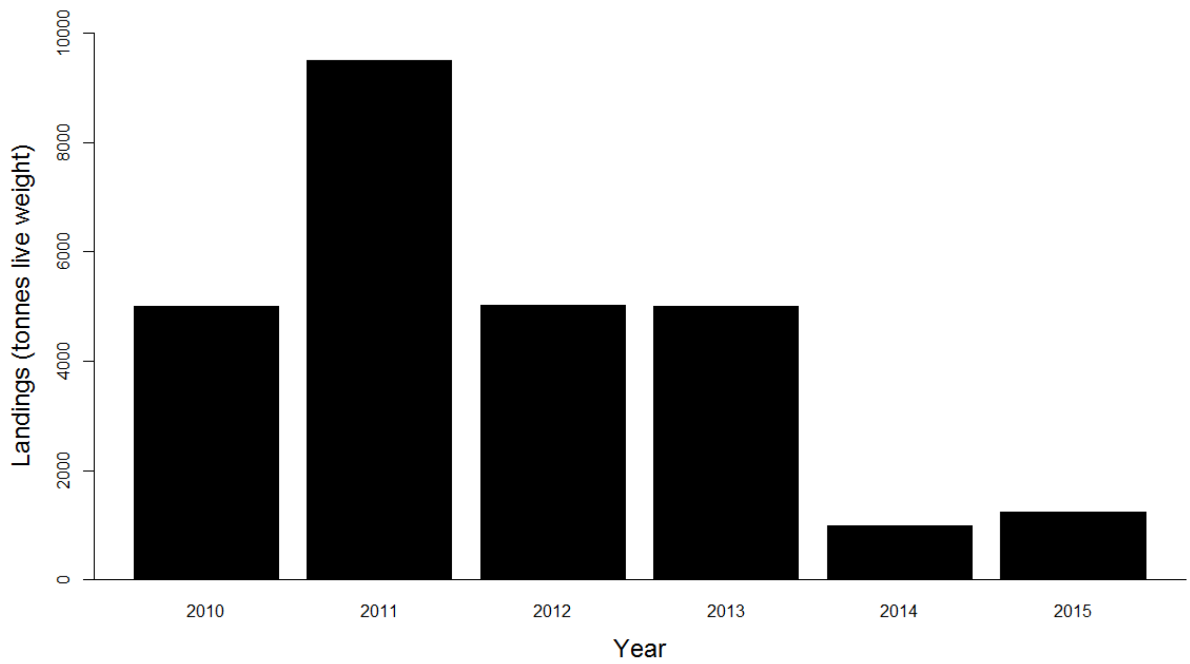

Figure 11: Estimated landings from the Isle of Man's territorial sea for 2010 - 2015. For 2010 – 2013 these values are estimates are derived from VMS data combined with logbook data and include only data where matches were found between logbooks and VMS records. For 2014 and 2015 the data was collected at the level of the territorial sea and are therefore actual values. Data are for calendar years (i.e. from January to December for each year), rather than fishing years.

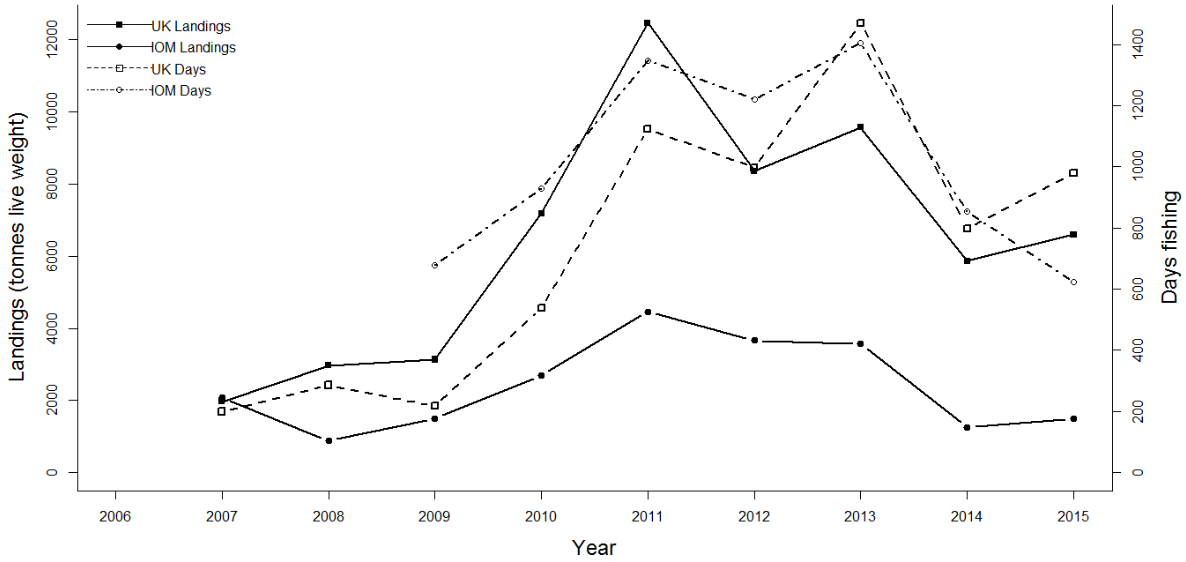

Figure 12: Landings from ICES statistical rectangles 36E5, 37E5 and 38E5 and days spent fishing for queen scallops by UK and IOM vessels. Days spent fishing by Isle of Man vessels are shown only from 2009 due to difficulty in accessing these data for earlier years. Data are derived from the iFISH database and are for calendar years (i.e. from January to December each year), rather than fishing years.

3.3 Stock assessment

Within the stock assessment unit (Isle of Man's territorial sea), the model output indicates that there was a general increase in fishing mortality between 2009 and 2013, while fishing mortality declined in 2014 and moderately increased again in 2015 (Figure 13). Abundance of recruits has shown a general downward trend since 2009 and is now at a similar level to that seen historically (e.g. prior to 2007) (Figure 15). Abundance of post-recruits has also shown a general downward trend since 2011 and stabilising in 2015 and 2016 at the levels of biomass similar to those observed prior to 2008 (Figure 16). Following five years of increasing biomass (2006-2010), total biomass has decreased during each of the subsequent six years (2011–2016), with landings remaining high despite annual decreases in biomass (Figure 14 and Figure 12). As landings exceeded surplus production in each of these six years a corresponding decline in biomass is evident for 2011 to 2016 (Figure 17).

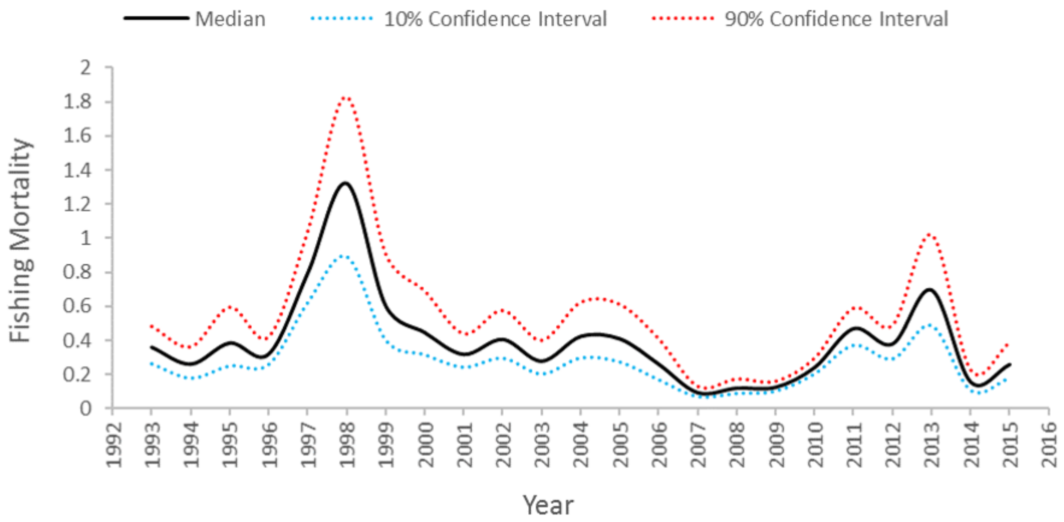

Figure 13: Fishing mortality for the stock assessment unit (Isle of Man Territorial Sea) estimated from harvest rate. Values are for fishing years (June to May).

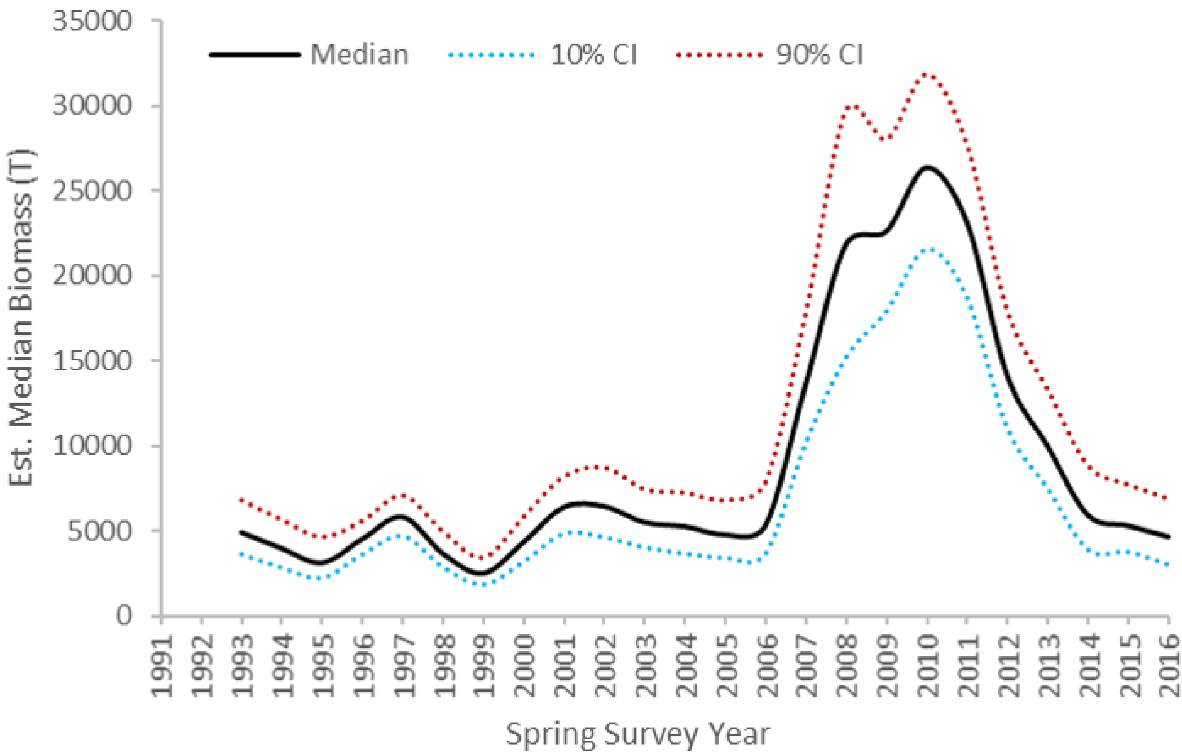

Figure 14: Total estimated biomass for the stock assessment unit (Isle of Man territorial sea) bootstrap results.

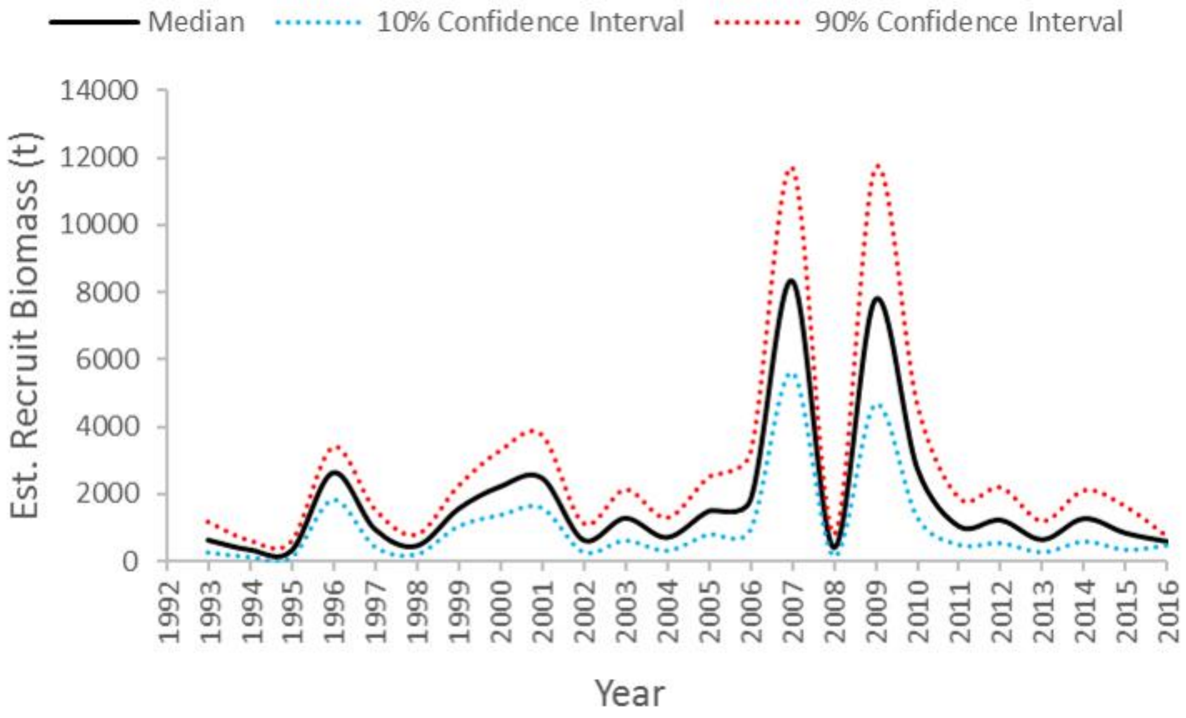

Figure 15: Estimated recruit biomass from the stock assessment unit (Isle of Man territorial sea) bootstrap results.

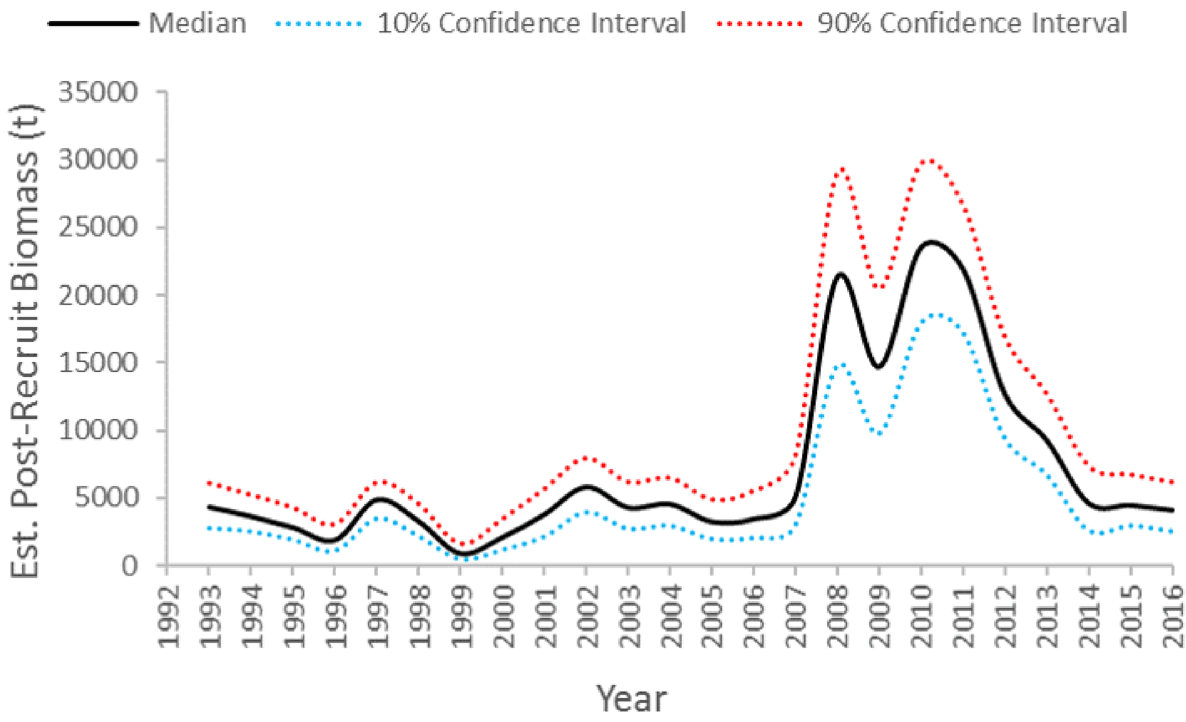

Figure 16: Estimated Post-recruit biomass from the stock assessment unit (Isle of Man territorial sea) bootstrap results.

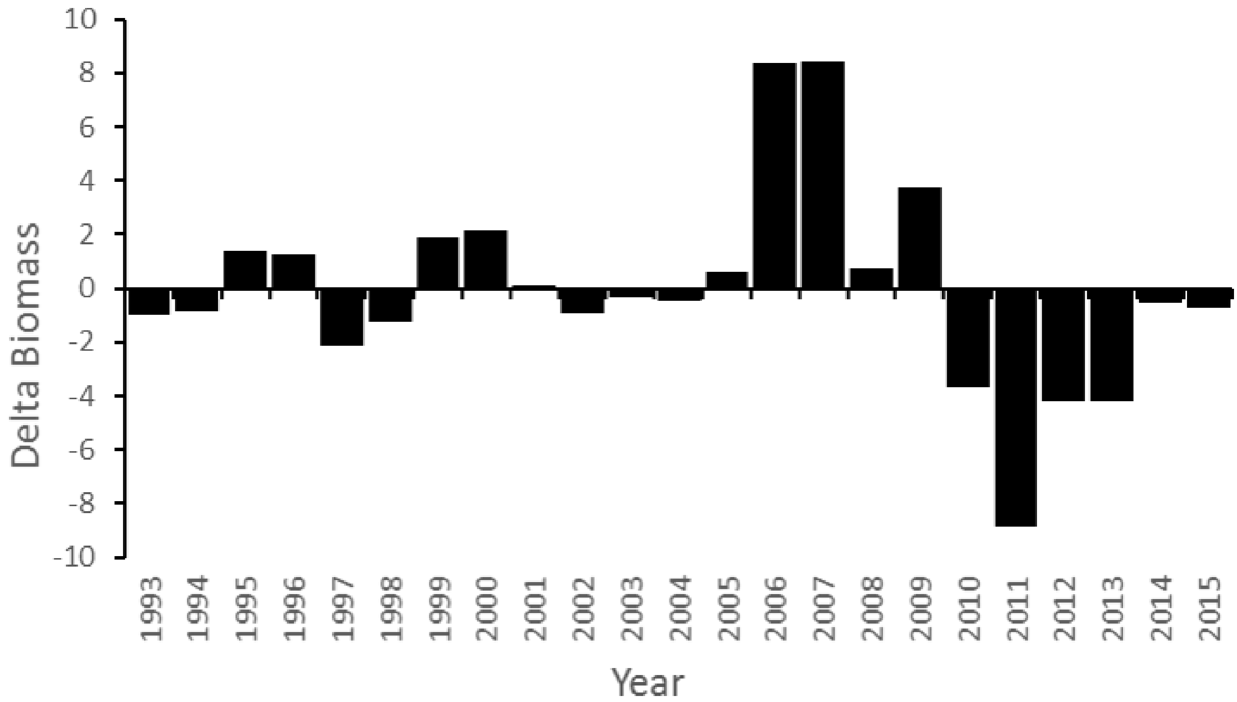

Figure 17: A graph showing annual change in total biomass (delta biomass) for the stock assessment unit (1000s tonnes). A negative delta biomass indicates that landings exceeded surplus production.

3.4 Closed Areas

Closed areas were established within each of the four main queen scallop fishing grounds around the Island (Figure 5). The primary purpose of these closures was to ensure that some areas of queen scallops, at high enough densities to spawn successfully (i.e. source areas), were safeguarded during the 2015/16 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.

In Closed Area I, situated to the west of the Island, the population sampled in 2016 had the highest abundance of all sites surveyed around the Island (38 queen scallops per 100 m^2). The largest proportion (92 %) of individuals sampled were within the size classes 55 – 70 mm which could provide an ongoing source of large, post-recruits for spawning. In addition, the abundance of queen scallops within this closed area had also shown an initial increase from 2015 (average of 25 queen scallops per $100m^2$) to 2016 (average of 38 queen scallops per $100m^2$).

In Closed Area II, situated to the south of the Island, for the population sampled in 2015 the largest proportion of queen scallops was within the size classes 55-65 mm whilst in 2016 the largest proportion was within the size class 65-75 mm. However, the abundance of queen scallops had decreased from 2015 to 2016. Densities in this area could have been affected by additional fishing effort that occurred following the reopening of the area for the king scallop season.

In Closed Area III, situated to the east of the Island, the population sampled in 2015 was composed predominately of larger, post-recruits from 60 – 70mm; providing a source of large, post recruits for spawning. In 2016 the population was still dominated by large post-recruits (from 55 – 70 mm) but there was also signs of some new recruitment (from 35 mm and over). The abundance of queen scallops had increased from 2015 (average 2.5 queen scallops per 100 m^2) to 2016 (average 6.8 queen scallops per 100 m^2).

In Closed Area IV, situated to the north of the Island, the population sampled in 2016 showed a good size range of individuals, with queen scallops ranging from 25-80mm. The overall abundance of queen scallops within this closed area was also high with an average of 20.6 queen scallops per 100m^2.

4. Discussion

4.1 Abundance indices

When scallop surveys commenced around the Isle of Man in 1992 queen scallop abundance was around nine times lower than at its recorded survey peak in May 2010 and remained at this low level until 1999. Recruit abundance then increased between 2000 to 2007 and was followed by an increase in post-recruit abundance from 2008 until 2010 (Figure 6).

Landings (referenced to ICES statistical rectangles 36E5 and 37E5 due to restrictions with historical data resolution) declined steadily between 1983 and 1996. Relatively low exploitation levels also occurred during the period 1999 to 2009. A sharp increase in landings was then observed from 2010 to 2013 and landings from these two ICES Rectangles have remained at above average levels in both 2014 and 2015 (despite a substantial reduction in landings from within the territorial sea) (Figure 9 and Figure 11).

The reason for the substantial increase in recruit abundance from 2000 to 2007 and the corresponding increase in post-recruit abundance from 2008 to 2010 is unclear. Possibilities include:

- The Alee effect (Gascoigne *et al*., 2009) indicates that the successful reproduction of scallops is dependent on their presence at a particular density. Scallop egg fertilisation success is likely to be higher when adults are present at higher densities (Stokesbury and Himmelman, 1993; Claereboudt, 1999). Therefore, the presence during this period of sufficient densities within key spawning areas may have enabled optimal fertilisation success within the fishery.
- The effect of fishing mortality in the wider stock unit (e.g. landings from outside the territorial sea from ICES Rectangles 36E5, 37E5 and 38E5) may impact on the larval supply into the territorial sea (see previous point). Previous modelling work has shown that the areas to the south and east of the Isle of Man (e.g. Anglesey) could provide an important source of larval supply to the Isle of Man's territorial sea (e.g. Neill & Kaiser, 2008). The low level of fishing activity that occurred outside the territorial sea prior to 2010 may have enhanced larval supply from those areas into the territorial sea.
- The low level of fishing effort and disturbance to benthic habitats observed pre-2010 may have been sustainable in relation to the preservation of the benthic habitats required for larval settlement (see Section 4.2 for further details).
- Environmental conditions during the period 2000 to 2010 were optimal for recruitment success (possibly during multiple spawning events each year) thereby causing a period of 'extraordinary' recruitment events that led to a large increase in post-recruit abundance in subsequent years.

In reality it is likely that these (and other such factors) interact on an annual basis to affect recruitment success and subsequent stock levels. The combination of factors that occurred during the period of increased abundance may have provided the optimal conditions required for an extraordinary recruitment event(s) to occur leading to a subsequent substantial increase in biomass (**Figure 18**).

4.2 Recruitment and benthic habitats

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 currently below the recommended biomass reference point, the stock (and associated fishery) is likely to be highly dependent on annual recruitment success to replenish the catchable biomass. Recruitment of scallops can 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.

For successful recruitment to occur it is essential that there is sufficient suitable habitat for settlement of young scallops and adequate protection of these areas to ensure that young scallops are not directly damaged by fishing activity which could reduce future growth and productivity (Beukers-Stewart & Beukers-Stewart, 2009). One of the threats to these habitats is the secondary effects of mobile fishing gear that could lead to reduced larval settlement in the future. 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 for queen scallops is associated with otter trawls, while over the wider area covered by the biological stock (i.e. Irish Sea) dredging constitutes a much greater proportion of the area of seabed swept and queen scallops landings. Whilst trawling is generally considered to be less damaging to benthic habitats than dredging (Kaiser *et al*., 2006; Hinz *et al.,* 2011), cumulative effects, within both the territorial sea and the wider Irish sea, from king scallop dredging (1st November and 31st May) may also impact benthic habitats in these areas. At fishing intensities (king and queen scallop fishing combined) 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.

Surveys specifically focused on quantifying juvenile queen scallop densities around the island will help forecast areas of high densities earlier than is currently possible with the dredge based stock assessment survey alone, where the catchability of recruits less than 35 mm is limited due to the specifications of the gear. A focused juvenile survey will allow areas of high density juvenile queen scallops to be identified earlier enabling closed areas promoting on-growing to be identified and protected whilst also helping to optimise/tune the recruit selectivity value currently used within the stock assessment model. For this purpose, an annual industry survey will be undertaken for the first time in 2016 to quantify juvenile queen scallops using a 2m beam trawl to estimate recruitment abundance around the Island to help improve estimates of pre-recruits and recruits.

4.3 Stock assessment

For the area of the territorial sea the median biomass for 2016 is estimated as 4678t (with a 10% and 90% confidence interval range of 3022t to 6928t, respectively), whilst for 2015 the estimated median biomass is 5328t (with a 10% and 90% confidence interval range of 3780t to 7749t, respectively).

The MSC process requires that a minimum and maximum biomass threshold is calculated for the stock. When the stock assessment unit was assessed at the previous extent (ICES rectangles 36E5 and 37E5) the minimum biomass threshold was estimated using analysis of historic biomass and landings data (Murray, 2013). This analysis indicated that 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 was recommended as a critical minimum threshold for biomass for the stock unit 36E5 and 37E5 (for the revised stock assessment unit of the territorial sea this figure would be around 6500t using data from the latest model to replicate the analysis). In terms of setting an appropriate harvest rate, analysis of the historic data indicates that when the stock is above the minimum biomass threshold 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).

These recommended thresholds (e.g. critical minimum threshold for biomass of 13000/6500t and harvest rate of ≤ 30%) are subjective and should be used by fisheries managers as a guide in implementing management measures for the fishery based on the overall trends indicated by the stock assessment model.

Analysis of the long term data series available for this fishery indicates that biomass is now estimated to be at a level similar to that sustained historically (annual average of 4873t for the period 1993-2006; 2014-2016). While estimated biomass for that period observed year on year fluctuations, the overall trend remained relatively stable with a seasonal average of around 1845t removed (range 886 – 3343 t for the period 1993-2006; 2014-2015) (**Figure 18**). At these low biomass levels the fishery would have been heavily dependent on annual recruitment success to allow biomass levels to increase. As the fishery experienced a significant increase in biomass in subsequent years this would indicate that at conditions experienced during that period, fishing at these levels did not negatively impact recruitment success in the long-term. It should be noted however that changes in ambient environmental conditions (e.g. sea temperature) and the level of fishing effort that the stock currently experiences outside of the territorial sea are likely to provide a different context for the present fishery than that which was observed historically.

As a direct relationship has yet to be found between spawning stock biomass and recruitment for scallops it is likely that biomass levels do not act in isolation to determine stock levels but rather that it is one of multiple factors that have threshold limits that affect stock biomass including:

- Spatial variation in local densities of spawning individuals (e.g. Allee effect) which impact spawning success
- The physical impact of fishing on the benthic habitats utilised by scallop larvae during settlement
- The impact of fishing outside the territorial sea which may impact larval supply into the territorial sea and
- The impact of ambient environmental factors (e.g. water temperature and chlorophyll levels)

-that interact to determine the success of annual recruitment to the stock. Identifying a single reference point that incorporates the correct combination of these factors will be difficult and may take many years. Therefore, the combination of low total biomass and the removal of a high proportion of biomass must continue to be interpreted as a high risk strategy for the fishery and one that will sustain only low annual landings.

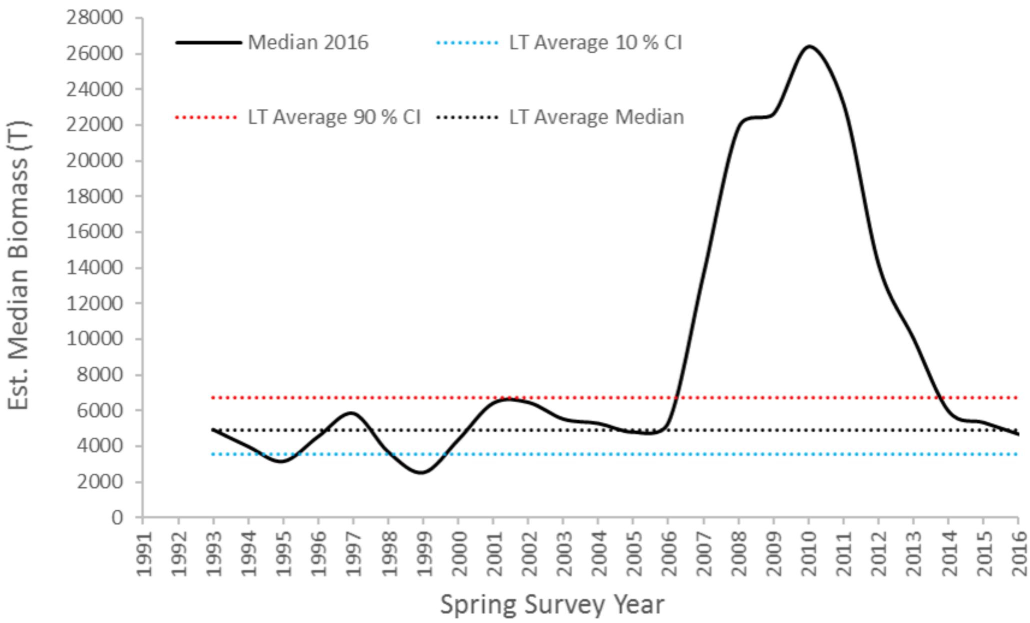

Figure 18: Estimated biomass for the territorial sea as predicted from the 2016 stock assessment model. The dotted lines show historic long-term average estimated biomass (black dotted line denotes the Median; red dotted line denotes the 90% Confidence Interval and blue dotted line denotes the 10% Confidence Interval) calculated using all data except the years 2007 – 2013. This highlights the extraordinary nature of the peak in biomass that occurred during that period

As seen in **Table 1**, for the five years that the stock assessment has been undertaken for the queen scallop fishery the TAC for the territorial sea has not been set in line with scientific recommendations. For the previous two years no fishing has been advised in order to promote the earliest recovery of the stock to levels above the minimum biomass threshold. However, for economic reasons a TAC for the territorial sea was advised by the QMB during these years on the basis that a 0t TAC is considered uneconomically viable for the long-term sustainability of the fishing industry. Should fishing occur again during the 2016/17 fishing season it is recommended that as the estimated stock biomass for 2016 is slightly lower than that predicted for 2015 that there is no evidence to support any increase in the TAC from the level set in 2015 (e.g. 1240t). Furthermore, as a precautionary approach, to try and stabilise biomass it is recommended that biomass removal is limited to 20% or lower of the estimated mean biomass for the territorial sea (e.g. ≤ 935t). It is also recommended that other management options (e.g. closed areas) should continue to be considered to help promote stock recovery. These measures also reduced the environmental footprint of the fishery in 2015 allowing areas of the territorial sea to remain unfished throughout both the queen and king scallop fishing seasons.

Table 1: A comparison of scientific advice and actual TAC/landings (2010-2016). Landings here are represented seasonally (1st June to 31st May); BM = biomass. [*The recommended scientific TAC was 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 rectangles equates to a TAC of 2500t for the territorial sea]

	Territorial Sea				36E5, 37E5 & 38E5
Year	Estimated BM	Scientifically advised TAC (territorial sea)*	Actual TAC (territorial sea)	Estimated BM Removed (%)	Additional landings
2012/2013	14167t	2500t	3500 – 4000t	28%	6425t
2013/2014	10000t	2500t	5000t	50%	7631t
2014/2015	5952t	None	1000t	16%	5561t
2015/2016	5328t	None	1240t	23%	6209t
2016/2017	4678t	935 – 1170 t	TBD	TBD	TBD

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, 2008). 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, 2008). Within the appendices of this report the outputs of the two model versions are detailed (Appendix, 2). A comparison of these outputs reveals that whilst the new model (version 4.3) consistently estimates biomass at a slightly lower 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 Stock assessment unit

Since the stock assessment was first undertaken in 2012 there has been a fundamental mismatch of data sources between:

- the management unit and the abundance index survey area (Isle of Man territorial sea),
- the area from which landings data are collated and the unit for stock assessment (prior to 2016: ICES rectangles 36E5 and 37E5) (Figure 3) and
- the area of the actual biological stock (Irish Sea).

The recent changes in the management of the fishery within the Isle of Man's territorial sea have widened the gap in this spatial mismatch. Whilst historically 50% of queen scallop landings from within the two ICES rectangles 36E5 and 37E5 were estimated to originate from inside the territorial sea and 50% from outside the territorial sea, during the last two fishing seasons, as a result of the management measures implemented within the territorial sea, this has changed to around 16% inside and 84% outside.

In order to try and reduce the impact of this disparity and mismatch the stock assessment unit for the 2016 model has been reduced to the level of the management and survey unit (territorial sea). It should be noted that any revision to the data inputted into the model (i.e. the inclusion or removal of survey stations or a change in the stock assessment unit) will lead to changes in the output of the stock assessment model and thus the graphs within this report will have different scales to previous reports although the overall trends remain consistent. In addition, the inclusion of each additional year of data can also lead to a slight retrospective change in the biomass estimate for the years prior.

Queen scallops within the Irish Sea are generally thought to consist of a single stock (Beaumont, 1982; Macleod *et al.*, 1985). Therefore, 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 actual area encompassed by the biological stock (i.e. 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 and this work involves multiple management jurisdictions (Section 1.3). 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.

4.5 Spatial variability in fishing mortality

Analysis exploring the effects of spatially heterogeneous fishing effort and fishing mortality within the stock assessment unit on the outputs of the stock assessment model will be required for the future. Changes in the spatial distribution of fishing effort have occurred following changes in both the stock and the management of the fishery within the territorial sea. The spatial distribution of the fishery during the 2015/16 fishing season largely focused on a discrete bed of large post-recruit scallops off the west coast of the Isle of Man within the fishing ground known as Targets. Approximately 77% of landings from the territorial sea during the 2015/16 fishing season were removed from this area (Station 5). Spatial patterns of fishing effort can be identified on an annual basis using Vessel Monitoring System (VMS) data that records the position of a vessel every 120 min. In order to explore these patterns in the future it would be useful to poll the vessels involved in the queen scallop fishery at a higher intensity (e.g. 30 min or 60 min) to allow more detailed analysis. Data that has been collected using GPS loggers (recording positions of a vessel every 30 seconds) and Daily Catch Returns (recording fishing activity on a tow by tow basis) can be used to compare to VMS and logbook (recorded at a daily level) data to assess the variability in estimates of fishing effort and its spatial variation in extended polling intervals compared to actual fishing effort recorded with GPS loggers and Daily Catch Returns.

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. Suitable areas can be identified from size-frequency analysis of the survey data from individual stations with areas with a large proportion of pre-recruits or recruits protected as 'on-growing' areas.

4.7 Dredge Cameras

In order to try and increase the amount of data that is collected during the April stock assessment survey this survey has been extended to 14 days. In addition, two dredge camera housings have been added to the dredge tow bar. These are positioned facing backwards with Dredge Camera 1 between Dredges 1 and 2 and Dredge Camera 2 between Dredges 3 and 4. This enabled the dredge tows to be viewed and ensure that the dredges are situated on the seabed and fishing correctly, should any technical issues be apparent on the video then the tow can be repeated. The video also provides a rapid visual assessment the seabed habitat at each tow to ensure that the tension on the teeth bars has been set appropriately and that the dredge contents reflects what was seen on the tow. The towing speed is however too fast to allow an estimation of scallop densities.

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.
- Changes in the proportion of landings from ICES Rectangles 36E5 and 37E5 originating from inside (16%) and outside (84%) the territorial sea as a result of management have led to the 2016 unit for the stock assessment model being revised to the level of the territorial sea to align with the area covered by the abundance index.
- The 2016 estimated median population biomass 4678 (t) remains below the minimum biomass threshold that was set as part of the MSC scheme.
- The estimated biomass for 2016 is lower than the estimated biomass for 2015. There is therefore no scientific evidence that the stock is able to support any increase in the TAC from the level set in 2015 (e.g. 1240 t).
- Furthermore, should fishing occur a more precautionary approach for the 2016/17 fishing season, limiting biomass removal within the territorial sea to 20–25% of the estimated median biomass (e.g. 935 – 1170t) is advised in order to try and further stabilise and/or promote increase in biomass.
- 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 continue to be considered annually.
- Low abundance of recruits at several survey stations has required plans to increase sampling effort of juvenile queen scallop to be developed. An annual beam trawl survey (which better targets recruits) will be undertaken across the territorial sea led by Industry in the last week of June 2016.
- The issue of latent effort within the fishery has now been addressed with a reduction in the number of eligible licenced vessels from 138 for the 2014/15 fishing season to 49 for the 2015/16 fishing season, following the introduction of a track record period.

- Whilst landings have substantially decreased in 2015, particularly within the territorial sea (1240t) where management measures were in place, landings from 36 and 37E5 (8033t) which covers the wider area of the biological stock are still above the long term average.
- Dredge Cameras have been fitted to the survey equipment to help improve confidence of industry in the results of the annual scientific survey.
- 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 2: The survey station sampling frequency for spring scallop surveys and extent of sampled sites; additional numbered survey stations for 2012 - 2016 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 2 for spatial locations). Stations used in the 2016 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** (red)	**X**	**X**					**X**	**X**	**X**	**X**		6 (+1)
1996	**X** (red)		**X**	**X**	**X**					**X**	**X**		**X**		6 (+1)
1997				**X**	**X** (red)					**X**	**X**		**X**		4 (+1)
1998			**X**	**X** (red)	**X** (red)					**X** (red)	**X** (red)		**X** (red)		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** (red)	**X**		**X** (red)	**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)
2016	**X**	**X**	**X**	**X**	**X**			**X**	**X**	**X**		**X**	**X**	**X**	48 (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
2012	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
2014	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
2016	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X

Year	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						
2013				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		
2015		X		X		X	X	X	X	X		X	X	X	X	X	X	X		X	X
2016	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.

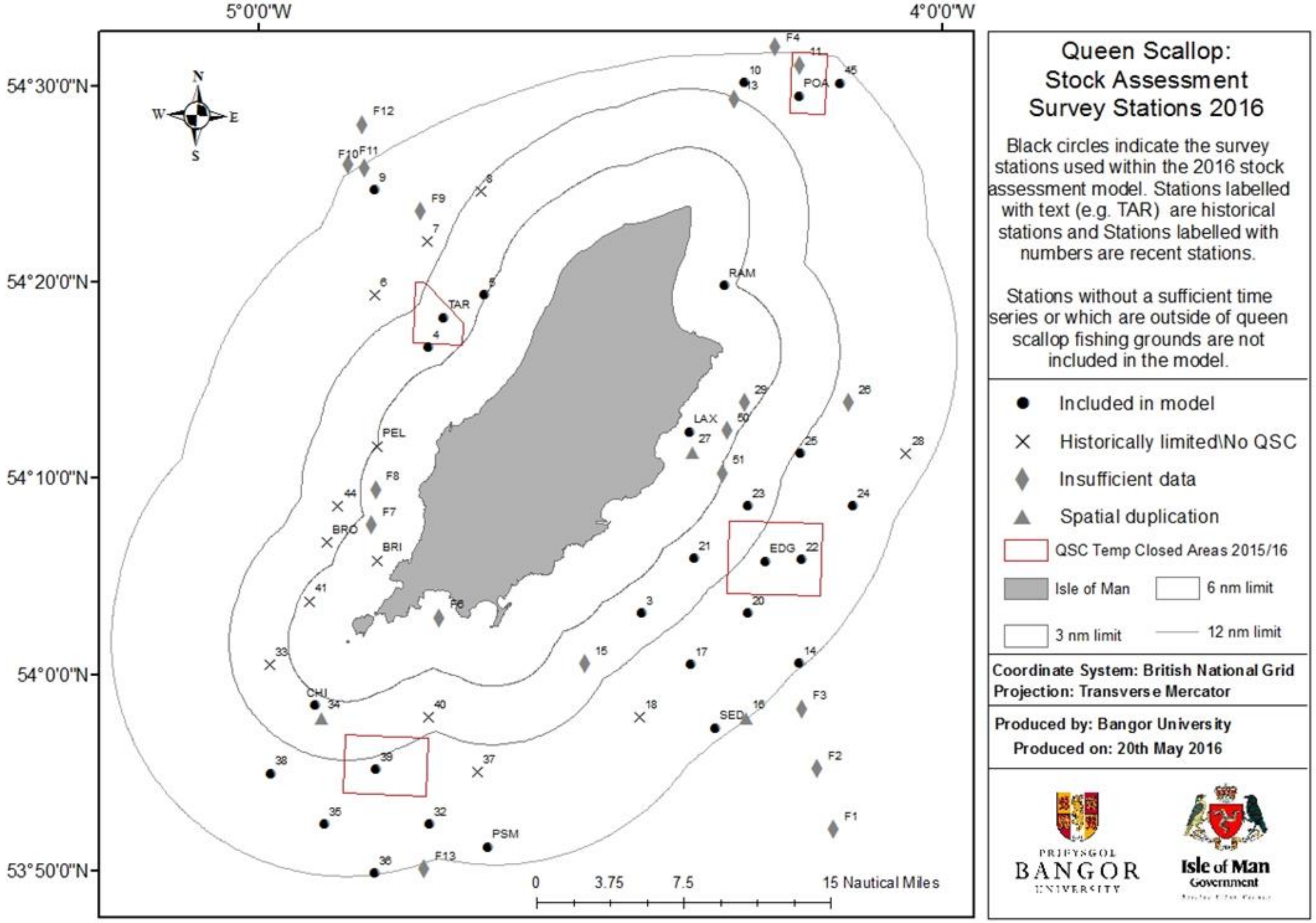

Figure 19: A map displaying the actual survey stations within the Isle of Man territorial sea used in the 2016 queen scallop stock assessment model and the primary reason why the remaining stations were excluded from the analysis. Named stations were first sampled from 1992 onwards, whilst numbered stations were first sampled from 2012 onwards. For 2016, the stock assessment presented in the main section of this report was undertaken for the Isle of Man territorial sea.

Table 3: Input data for the original version of the 2016 queen scallop stock assessment model for territorial sea area

	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	0.018732	0.039115	38.0408096	1.90204048	0.039115	0.018732	0.2	0.35
1994	15.86583449	174.5156615	0.01832	0.043612	20.3148754	1.01574377	0.043612	0.01832	0.2	0.35
1995	15.02050842	127.1489703	0.017113	0.043411	23.69219107	1.184609554	0.043411	0.017113	0.2	0.35
1996	46.91394182	77.46436025	0.017199	0.039088	48.30191459	2.415095729	0.039088	0.017199	0.2	0.35
1997	30.13695148	337.8036495	0.018163	0.040179	83.21931828	4.160965914	0.040179	0.018163	0.2	0.35
1998	31.46216705	355.6560054	0.014686	0.050585	61.85181766	3.092590883	0.050585	0.014686	0.2	0.35
1999	35.29379961	33.81202304	0.014428	0.041646	51.80315223	2.590157611	0.041646	0.014428	0.2	0.35
2000	114.2770179	250.3250707	0.017139	0.03518	59.96161082	2.998080541	0.03518	0.017139	0.2	0.35
2001	192.7072587	293.774687	0.018308	0.037457	57.95061044	2.897530522	0.037457	0.018308	0.2	0.35
2002	44.44380737	269.4850984	0.013478	0.03965	56.71526744	2.835763372	0.03965	0.013478	0.2	0.35
2003	106.7079497	411.692814	0.017501	0.039875	38.37988826	1.918994413	0.039875	0.017501	0.2	0.35
2004	87.83028495	507.586832	0.014064	0.040072	49.53094093	2.476547047	0.040072	0.014064	0.2	0.35
2005	224.3407131	108.3704358	0.017006	0.036403	52.10235702	2.605117851	0.036403	0.017006	0.2	0.35
2006	111.7935305	69.62017932	0.018102	0.035319	40.2861761	2.014308805	0.035319	0.018102	0.2	0.35
2007	242.4880336	157.6293945	0.016078	0.039473	50.21882323	2.510941161	0.039473	0.016078	0.2	0.35
2008	21.61892621	581.4203338	0.0141	0.0436	50.97888951	2.548944475	0.0436	0.0141	0.2	0.35
2009	135.1149428	1282.488027	0.0186	0.0385	82.32115104	4.116057552	0.0385	0.0186	0.2	0.35
2010	102.6363772	1642.350555	0.0136	0.0401	149.248437	7.46242185	0.0401	0.0136	0.2	0.35
2011	42.4943261	877.5682037	0.016	0.0424	189.0436321	9.452181604	0.0424	0.016	0.2	0.35
2012	57.00438917	1229.42525	0.015086	0.042656	105.9563772	5.297818862	0.042656	0.015086	0.2	0.35
2013	35.82450375	777.9523314	0.014506	0.042749	116.9628099	5.848140494	0.042749	0.014506	0.2	0.35
2014	74.98972325	312.374459	0.015673	0.042059	23.77634407	1.188817203	0.042059	0.015673	0.2	0.35
2015	40.79927292	212.3110724	0.016412	0.03317	37.68412127	1.884206063	0.03317	0.016412	0.2	0.35
2016	31.45162555	289.7213742	0.015537	0.033763	0	0	0.033763	0.015537	0.2	0.35

Table 4: 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%) from 2016 Stock Assessment Model for territorial sea area.

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	33.4607	110.1625	0.3592	4933.8
1994	18.4346	82.9969	0.2603	3988.7
1995	18.0581	64.5284	0.3837	3150.1
1996	153.383	47.7432	0.3197	4552.1
1997	52.3262	120.958	0.7938	5843.6
1998	30.7757	64.2903	1.3216	3678.2
1999	107.761	20.8895	0.6015	2523.7
2000	129.6985	58.9749	0.4457	4370.1
2001	135.717	100.535	0.3173	6425.5
2002	46.6846	146.4245	0.405	6462.6
2003	73.1485	107.0145	0.2779	5523.4
2004	50.1801	113.126	0.4223	5282.4
2005	87.8446	88.775	0.4089	4795.1
2006	101.104	97.167	0.2598	5350.8
2007	519.7435	128.2315	0.0927	13656.2
2008	28.5412	489.83	0.119	21871.8
2009	419.7235	381.8105	0.1246	22637.9
2010	202.5125	587.3575	0.2408	26404.2
2011	64.724	517.858	0.4687	23167
2012	81.0424	297.557	0.3788	14167.2
2013	44.1618	216.8695	0.6946	10014.2
2014	80.9871	109.366	0.1552	5952.4
2015	50.7088	133.966	0.2579	5327.7
2016	37.6063	120.972	-	4678.4

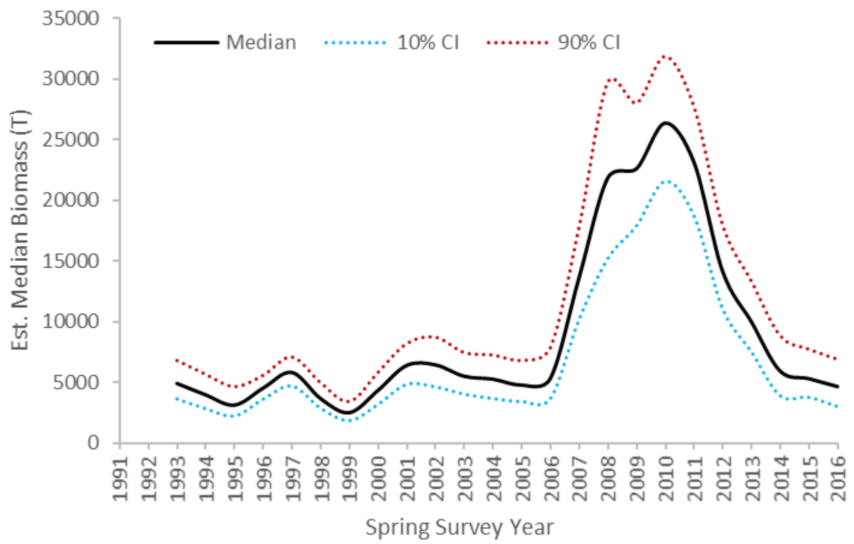

Figure 20: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5 and 37E5) bootstrap results. From 2016 Stock Assessment Model (CSA Version 3.1.1)

Table 5: 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%) from 2016 Stock Assessment Model for territorial sea area.

Fishing Season	Recruit abundance (thousands)	Post-Recruit abundance (thousands)	Fishing mortality (harvest rate)	Total median biomass (t)
1993	36.9143	117.9345	0.33161	5308.6
1994	19.5442	91.3703	0.23662	4345.6
1995	20.3035	71.8914	0.35104	3467.6
1996	157.3915	53.162	0.30835	4755.7
1997	69.3628	126.005	0.66338	6339.9
1998	43.1368	82.6897	0.82281	4817.4
1999	86.0034	45.4346	0.59688	3138.3
2000	149.4705	59.4546	0.39927	4657.7
2001	155.097	114.6985	0.2843	7147.6
2002	52.7321	166.371	0.35407	7304.4
2003	80.6696	126.1515	0.24197	6437.3
2004	57.3974	132.9745	0.35869	6144.6
2005	96.8851	109.081	0.34692	5624.7
2006	96.8307	119.1765	0.24314	5956.4
2007	488.799	138.663	0.09631	13418.9
2008	29.5921	469.044	0.125	20882.7
2009	433.3595	361.142	0.12752	21778.9
2010	210.3155	570.5685	0.24634	25770.3
2011	79.2272	503.509	0.46363	22631.7
2012	89.3786	300.3335	0.37344	14187.3
2013	45.3273	219.986	0.70616	10042.7
2014	75.3116	107.202	0.16328	5688.3
2015	50.1461	126.854	0.28107	5032
2016	33.9113	109.781	-	4236.6

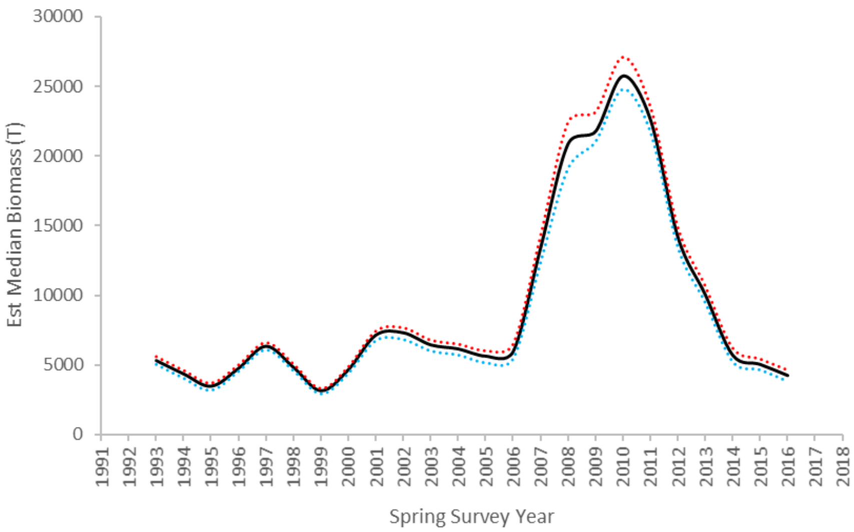

Figure 21: Total estimated median biomass for the stock assessment unit (ICES Rectangles 36E5 and 37E5) MCMC results. From 2016 Stock Assessment Model (CSA Version 4.1)