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**Management evaluation report of a limited king scallop
(*Pecten maximus*) fishery within Ramsey Bay fisheries
management zone**

(Feedback to the industry)

July 2014

(Revised Final Report)

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To cite this report: Dignan, S.P., Bloor, I.S.M., Murray, L.G. and Kaiser, M.J. (2014). Management evaluation report of a limited king scallop (*Pecten maximus*) fishery within Ramsey Bay fisheries management zone. Fisheries & Conservation Report No. 34, Bangor University. pp. 24.

Executive Summary

In November 2009 Ramsey Bay was closed to dredging for scallops as stocks were seen to have become depleted. Later the Ramsey Bay Marine Nature Reserve (RBMNR) was created, part of which (45.9 km²) was designated a fisheries management zone (FMZ). In 2013 a lease to manage the FMZ was granted to the Manx Fish Producers Organisation (MFPO). Subsequently, scientific surveys showed scallop stocks were increasing so a decision was made by the MFPO to undertake a limited fishery in the area. Following scientific advice the MFPO decided to restrict the fishery to an area of approximately 20% (9.1 km²) of the FMZ and imposed a Total Allowable Catch (TAC) of 580 x 40kg bags. In addition, for economic, enforcement and ecological reasons, the MFPO decided that the fishery should be prosecuted by only three of its members' boats and the profits shared as a dividend by its members. In total approximately 181 hectares (1.81 km²) of seabed were affected by the fishery (approximately 2.9% of the FMZ). Catch rates from the fishery averaged 1.37 bags per dredge per hour. Scallops from Ramsey Bay were on average seen to be larger and faster growing than the island-wide average for autumn 2013, with individuals reaching MLS (110 mm) at a lower age. Indeed only 14% of observed catches during the fishery were below Minimum Landing Size (MLS). Yields from the fishery were approximately 27.5kg of scallop meat or circa £300 per hectare. The initial intention had been to fish the area in May 2013 when the price for scallops was approximately £9.50 per kg meat weight. However, the MFPO, in deciding to delay the fishery until December 2013, achieved a price of £13.50 per kg meat weight and a gross profit 42% greater than would have been achieved had the same catch been landed in May. Total Green House Gas (GHGs) emissions resulting directly from the fishery would have been in the region of 3.6 tonnes, of which 3.54 tonnes were estimated to comprise CO₂. The calculated edible protein Energy Return On Investment (ep-EROI) ratio for the Ramsey Bay fishery was approximately 0.712 which meant that, for every kg of chemical energy expended, in the form of fuel, 712 grams of edible energy, in the form of protein were obtained. Overall the fishery in Ramsey Bay was as much as nine times more energy efficient than the Manx king scallop fleet as a whole.

Table of Contents

1. Introduction	1
1.1. The Fishery	1
1.2. Data recorded during the fishery.....	2
2. Results.....	3
2.1. Area affected.....	3
2.2. Size Frequency Distribution	6
Age Frequency Distribution	6
2.4. Size and Age	7
2.5. Catch Depletion Rate	9
2.6. Economics of the fishery.....	10
2.6.1. Yields from the fishery	10
2.6.2. May Vs December Fishery.....	10
2.6.3. Advantages of the Contracting Process	10
2.7. Environmental Impacts of the Fishery	12
2.7.1. Green House Gas (GHG) emissions	12
2.7.2. Energy Return on Investment (EROI).....	13
3. Discussion.....	15
3.1. Area affected.....	15
3.2. Size and Age Frequencies.....	15
3.3. Catch Depletion Rate	16
3.3. Economics	17
3.3.1. May Versus December Fishery	17
3.3.2. Advantages of the contracting process	17
3.4. Environmental Impacts and EROI	18
3.5. Video Sled Survey.....	18
4. References	19
5. Appendix	21

1. Introduction

In November 2009 all scallop fishing within Ramsey Bay, Isle of Man, was suspended following evidence that stocks within the bay had fallen below an abundance that was economically viable to fish. Subsequently the Ramsey Bay Marine Nature Reserve (RBMNR) was created and, on 1st January 2012, an area of 45.9 km² was designated as a fisheries management zone (FMZ) (Figure 1). A lease was given to the Manx Fish Producers Organisation (MFPO) to manage fishing for scallops by its members within the FMZ; with the proviso that the ecological integrity of the FMZ should be maintained. Surveys of scallop abundances within the FMZ were intermittently conducted aboard both F.P.V. Barrule, R.V. Prince Madog and commercial fishing vessels in order to establish whether stocks within the FMZ exhibited signs of recovery. In early 2013 these surveys showed that scallop abundances were increasing within the bay and the MFPO expressed an interest in reopening the fishery. While the original intention was to open the fishery in May 2013 the MFPO decided, considering both the economic implications and life history traits (i.e. the ripening of the roe) of king scallops, to postpone the fishery until December 2013.

1.1. The Fishery

The MFPO, following advice from Bangor University and DEFA adopted a precautionary approach and prosecuted a highly controlled fishery within the FMZ. The fishery was limited to a box in the south-east corner of the FMZ, comprising approximately 20% of its total area (Figure 1), which from preliminary surveys had shown the highest densities of scallops (Appendix 3). MFPO members, taking into account factors such as fuel costs, enforcement concerns, potential interference between vessels, and the impact on public opinion, decided that it would be best if fishing were conducted by a limited number of vessels; the resulting profits would then be shared between MFPO members as a dividend. Consequently, following a tendering process, three vessels - Constant Friend (PL 168), Helen M (RY 57) and Peter M (PL 25) - out of a potential fleet of approximately 28, were selected to prosecute the fishery. A Total Allowable Catch (TAC) of 580 x 40kg bags was agreed prior to the commencement of the fishery (a total of 635 bags were landed as the bags were light on average @ c. 38kg per bag).

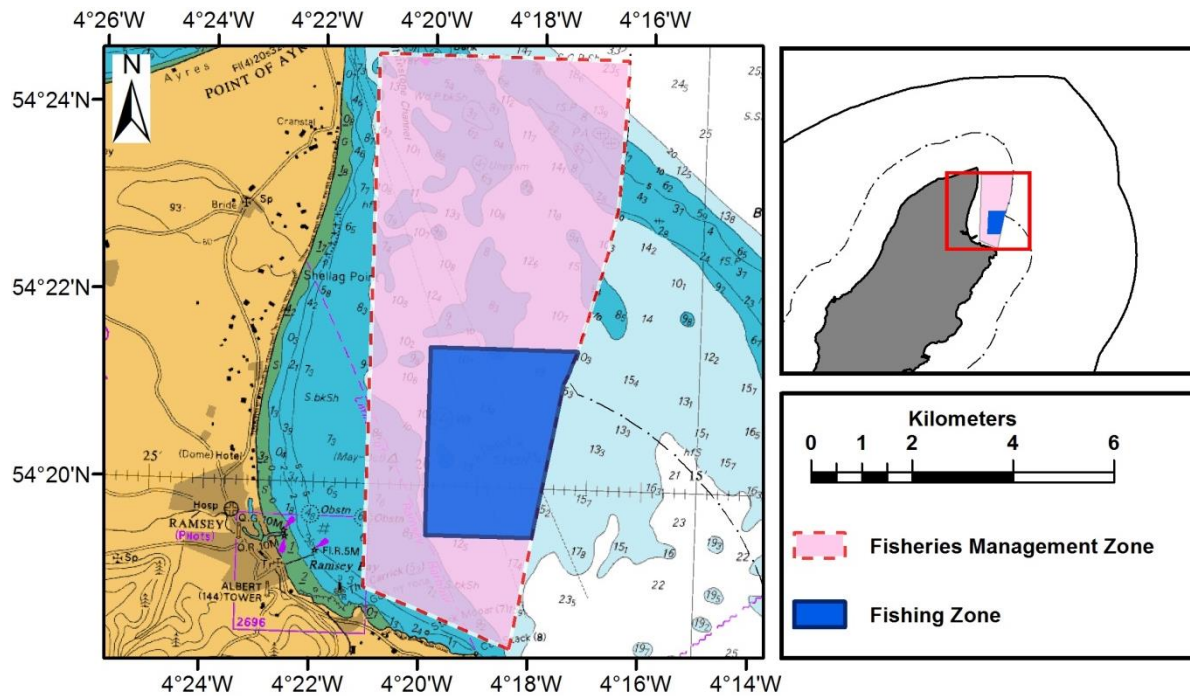


Figure 1. Ramsey Bay Fisheries Management Zone (FMZ) (displayed in pink) and the area where fishing activity was permitted during the December 2013 fishery (displayed in blue).

1.2. Data recorded during the fishery

Vessels participating in the fishery were required to carry GPS loggers, with a 5 second polling interval, in addition to their Vessel Monitoring System (VMS). These loggers were necessary in order to compensate for the fact that the 2 hour polling interval of VMS describes vessel movements at too low a resolution for fishing effort to be accurately mapped within the limited confines of the fished area. The data obtained from these loggers allowed the spatial distribution of fishing effort during the fishery to be represented at a fine scale. Additionally, fishers were requested to record the start and end coordinates, time, and catch for each tow on a log sheet. Observers from Bangor University and DEFA were also present aboard one of the vessels for an entire fishing trip to collect data that related to the size and ages of the scallops and the proportion of undersized animals caught in the dredges.

2. Results

2.1. Area affected

Approximately 171 hectares of seabed were dredged during the fishery; note this figure is for the dredges only and does not include the effects of the dredge bar of which only the rubber wheels either end are in contact with the seabed (Table 1). The width of dredge bar rollers are non-standard but in the case of vessels fishing 5 dredges a side would be expected to be c. 10 – 12 cm. Therefore, the impact of the dredge bar rollers would have contributed an additional area of approximately 5.8% to the total area impacted by the fishery. The total swept area of seabed comprised approximately 3.7% (total area dredged) of the FMZ; however, when the additional impact of the dredge bar rollers was included and an adjustment made for tracks that repeatedly crossed the same area of seabed, this figure dropped to 2.9% (actual area impacted). For the Fishing Zone, delimited on the basis of the preliminary survey in September 2013, the corresponding figures were 18.8% (total area dredged) and 14.5% (actual area impacted) respectively (Table 1). Considering that the FMZ represents less than 50% of the entire RBMNR the area affected was minimal in terms of the reserve as a whole. In addition, fishing activity was not dispersed across the Fishing Zone rather it was targeted at areas where abundances were highest (Figure 2). Catch rates across the fishery averaged 13.65 ± 3.84 bags per hour which, taking into account the fact that each vessel fished ten dredges, equated to approximately 1.37 bags per dredge per hour (Table 2).

Table 1. Summary table of the spatial extent of the seabed affected by scallop dredging and the average number of bags per 100m² dredged during the December 2013 fishery in Ramsey Bay FMZ.

Area affected	Tows	Bags	km ² dredged	Av. Bags 100m ⁻² dredged
Total	48	636	1.71	0.036
		% of		
	km²	FMZ	% of allowed area	
Area of FMZ	45.9	-	-	
Area of Fishing Zone	9.1	19.8%	-	
Total area dredged*	1.71	3.7%	18.8%	
Actual area impacted*	1.32	2.9%	14.5%	

*Area dredged is the area covered by the mouth of the dredges plus the additional width of the bar taking into account instances where dredges repeatedly impact the same place.

Table 2. Average tow duration and catch rates per vessel during the December 2013 fishery in Ramsey Bay FMZ. (Note all vessels utilised 10 dredges so per dredger rate = Catch Rate / 10 dredges)

Catch Rates	Minutes		Bags/Hour	
	Tow Duration	Standard Deviation	Catch Rate	Standard Deviation
Average	56	12	13.65	3.84

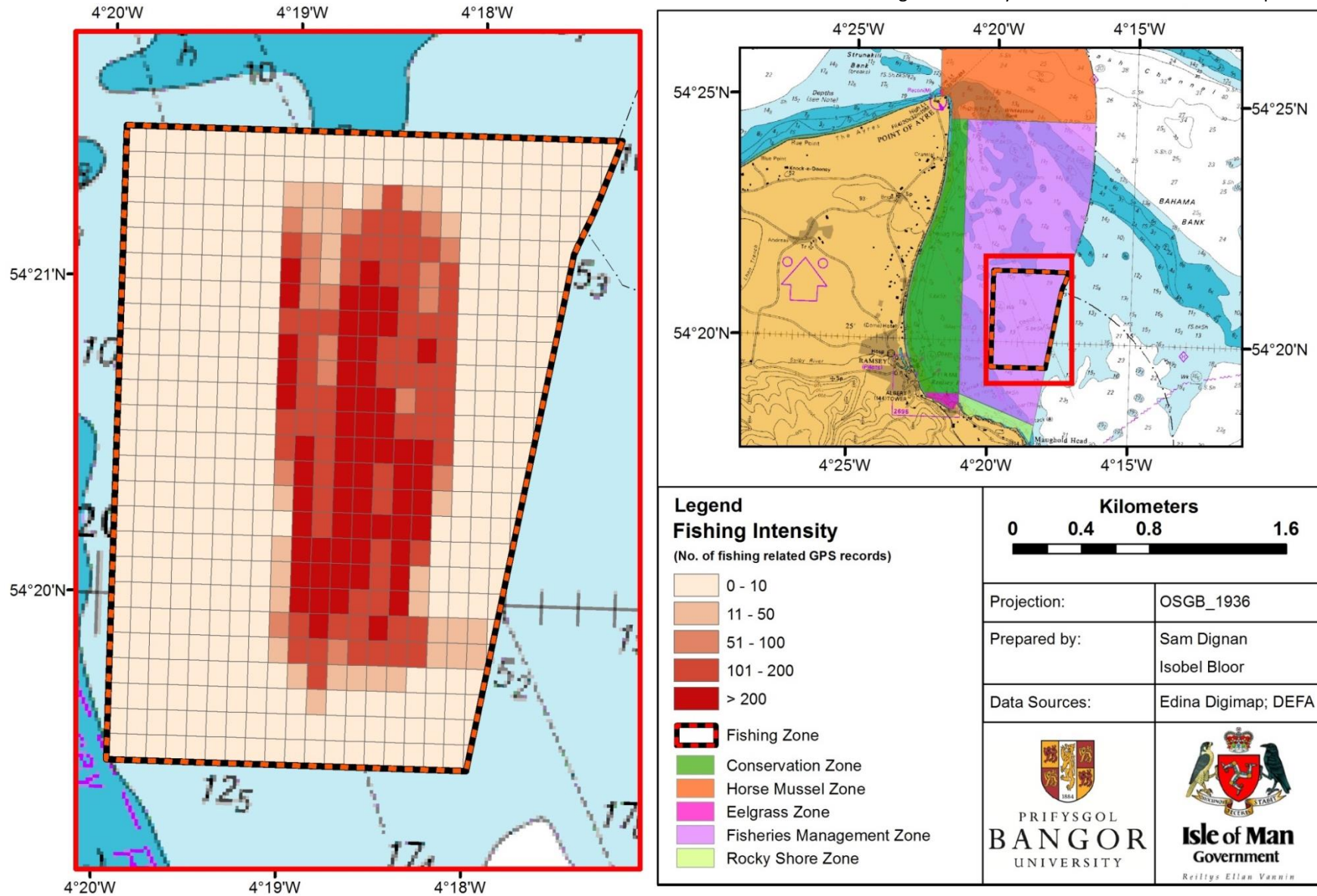


Figure 2. Fishing intensity, based on the number of fishing related GPS reports, during the December 2013 fishery in Ramsey Bay FMZ. (Note GPS positions were recorded every 5 seconds and were attributed to fishing activity based both on start and end times and on vessel speeds).

2.2. Size Frequency Distribution

The size frequency distributions of scallops landed from Ramsey Bay showed a greater percentage of larger individuals when compared to other sites from around the Island (Data taken from Sept 2013 scallop survey). The dominant size-class in Ramsey Bay (>40% of individuals landed) was 120 to 130 mm, while the 110 to 120 mm size-class contributed substantially more to populations of scallops elsewhere around the Island (Figure 3). During the Ramsey Bay fishery scallops below Minimum Landing Size (MLS) (110mm) comprised only 14% of catches recorded by observers. The proportion of <MLS scallops was much lower than compared to the size frequency distribution of scallops sampled from other areas around the Isle of Man (based on surveys undertaken in September 2013).

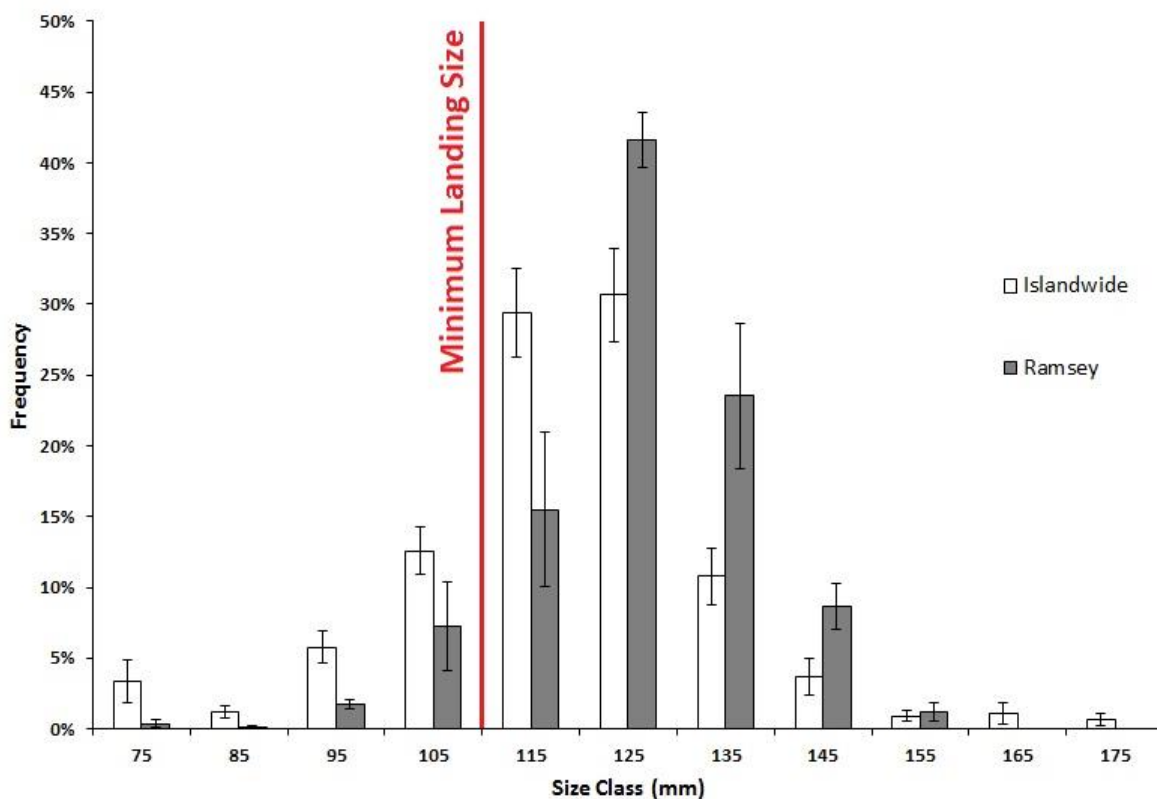


Figure 3. Size frequency distributions of scallops from within Ramsey Bay (data from both September 2013 scallop survey and December 2013 fishery) and island-wide excluding Ramsey Bay (data from September 2013 scallop surveys aboard the RV Prince Madog and the FPV Barrule). Error bars show standard error.2.3.

Age Frequency Distribution

Scallops landed from Ramsey Bay were, for the majority, in either the 3 or 4 year class such that these two classes combined made up over 70% of landing compared to approximately

43% island-wide. In sites around the Island, the age-class structure of scallop populations was more evenly distributed with scallops older than 4 years being a more prominent cohort of the population (Figure 4). In addition, within Ramsey Bay, pre-recruits (i.e. scallops in the 1 and 2 year classes) comprised a relatively small proportion of the catch when compared to catches island-wide during the September survey.

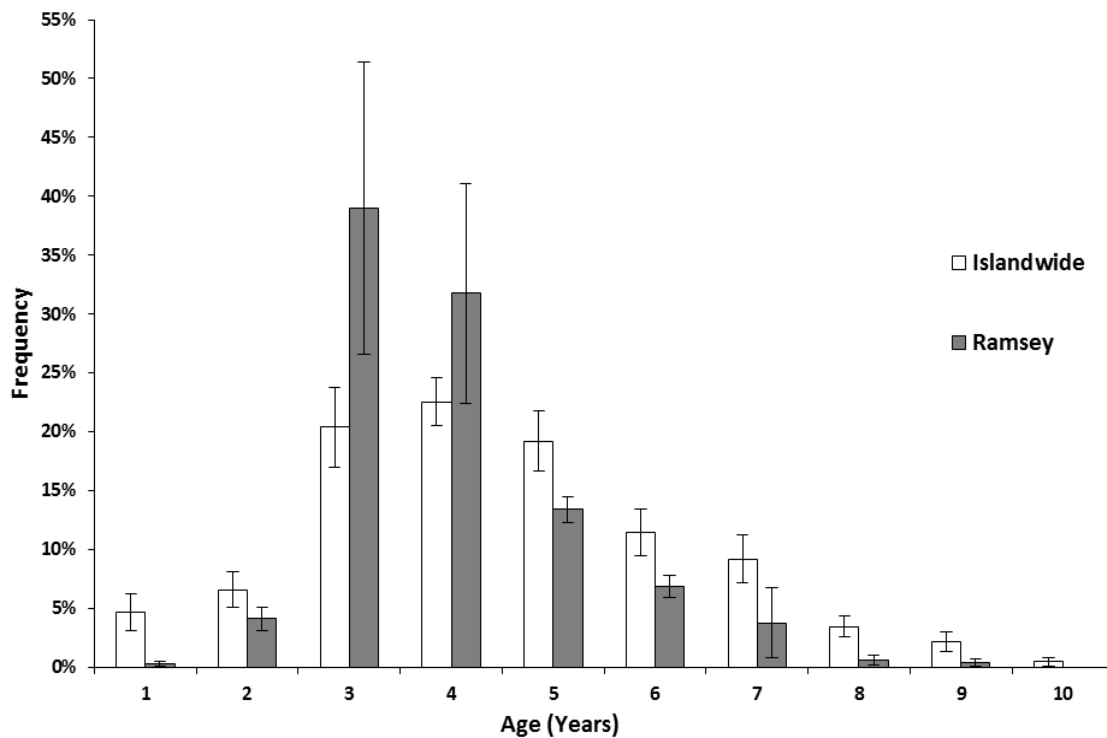


Figure 4. Age frequency distributions of scallops from within Ramsey Bay (data from both September 2013 scallop survey and December 2013 fishery) and island-wide excluding Ramsey Bay (data from September 2013 scallop surveys aboard the RV Prince Madog and the FPV Barrule). Error bars show standard error.

2.4. Size and Age

Initially data was pre-treated to account for variations in scallop aging techniques; this consisted of the removal of all records in excess of two standard deviations from the mean for each age class. The number of records removed from the Ramsey Bay and island-wide datasets were 68 (of 1239) and 80 (of 2353), respectively. Subsequently, von Bertalanffy's growth equation [$L_T = L_{\infty} [1 - e^{-k(t - t_0)}]$, where L_T = the mean length (cm) at age t (years), L_{∞} = the length on the y axis at which the asymptote is reached i.e. where length stops increasing, and t_0 is the theoretical age at width zero (year)] was used to describe the mean width at age relationships of scallops from both within and without Ramsey Bay. The non-linear curve fitting program in SPSS (IBM v.22) was used to fit the equation with Figure 5

showing the resultant growth curves. Within Ramsey Bay scallop growth was described by the equation $L_T = 140.8[1 - e^{-(0.547(t+0.4))}]$ ($r^2 = 0.991$) while average growth at the other sites around the Island, during the September 2013 scallop survey, was described by $L_T = 132.3[1 - e^{-(0.522(t+0.039))}]$ ($r^2 = 0.978$). The data suggests that on average Ramsey Bay scallops grow more quickly, reach MLS sooner and continue to a greater maximum size (Figure 5).

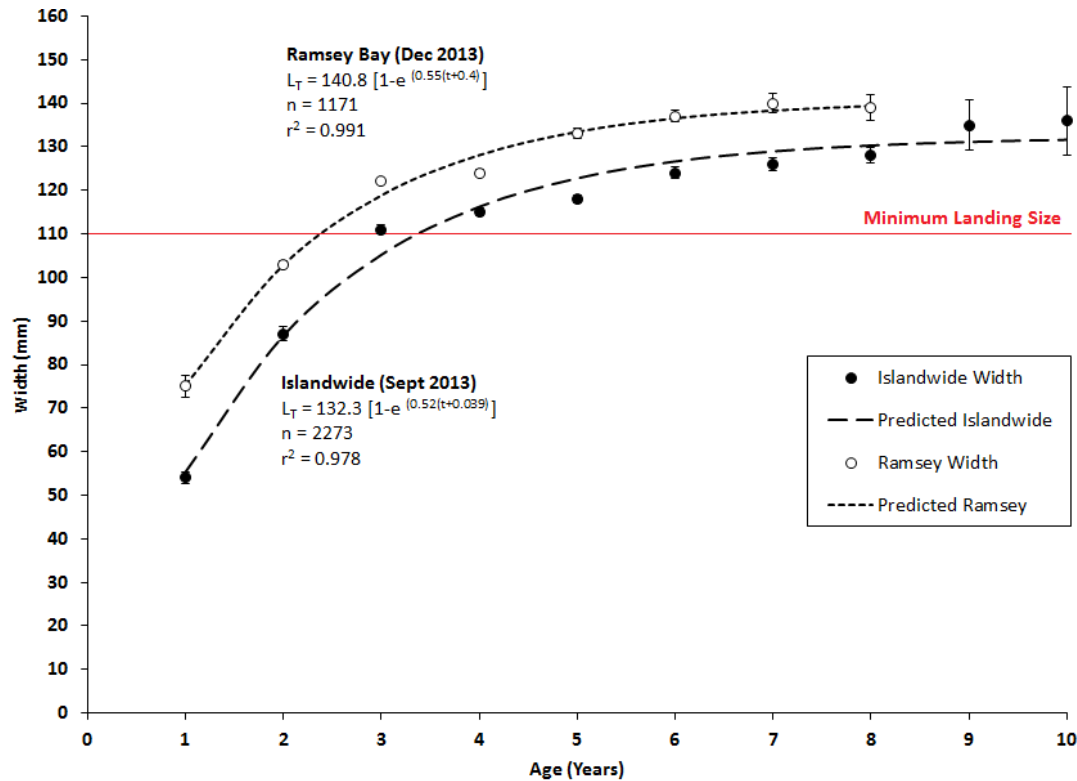


Figure 5. von Bertalanffy growth curves for king scallops (*P. maximus*) around the Isle of Man. Growth curves depict the average growth rate of scallops at sites around the Island sampled in September 2013 and the growth rate of scallops from the December 2013 fishery in the Ramsey Bay FMZ. Error bars show 2 standard errors.

However, there were two months between these two datasets being recorded and as a result growth will have occurred in the interim, potentially contributing to the Ramsey Bay scallops being comparatively larger. In addition, what is effectively compared in this instance is an exploited and an unexploited area. Ramsey Bay scallops may therefore be able to achieve greater sizes earlier as a result of reduced physical stress associated with the exclusion of fishing effort. Previous studies have suggested that the physical damage inflicted by scallop dredging has a negative effect on meat weight in scallops on chronically fished areas versus areas closed to fishing (Hiddink *et al.*, 2006).

2.5. Catch Depletion Rate

In order to investigate if Catch Per Unit Effort (CPUE) decreased as the fishery progressed it was necessary to remove “noise” from the dataset. This “noise” is related to the effects of a number of factors such as, differing catch rates among vessels and the fact that a fisher is free to move to a new area as catch rates decline. As resources in an area become depleted and CPUE falls a fisher may react by doing one of two things: (1) remain in that area and increase fishing effort to maintain his total catch, with an accompanying decrease in CPUE or (2) move his effort to a new area in search of higher densities of target species and hence increased CPUE. This transfer of effort between areas can maintain CPUE in the face of decreasing abundance and make actual changes on the ground difficult to detect. In this instance spatial variation in CPUE was accounted for by standardising based on the average easting and northings for each tow, with the resulting decline in CPUE evident in Figure 6. More detailed explanations of the methods and results of the modelling performed are presented in (Appendix 1).

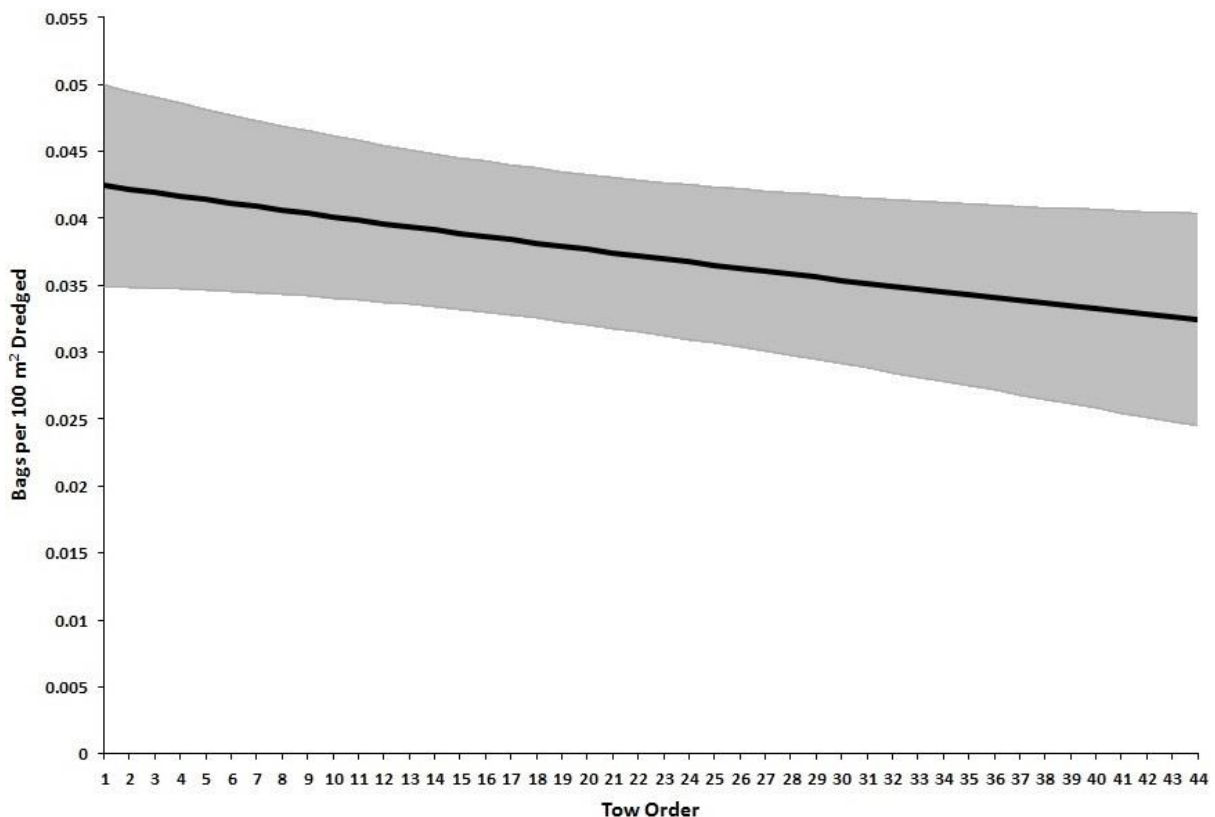


Figure 6. CPUE, in bags per 100m² dredged, during each tow of the December 2013 fishery in Ramsey Bay FMZ based on data standardised to remove position and vessel effects. Shaded area indicates ± 2 standard errors.

2.6. Economics of the fishery

2.6.1. Yields from the fishery

There were a total of 48 tows completed in the fishery with the average yield being approximately 136kg live weight of scallops per hectare. The average meat to live weight ratio was 0.2024, or just over 20%, meaning approximately 27.5kg of scallop meat was yielded per hectare dredged. Costs were paid on a per kilogram live weight basis and the price achieved for the catch was £13.50 per kg meat weight. After all costs had been deducted the fishery realised a net profit of just over £300 per hectare, with returns being split between members of the MFPO as a dividend.

2.6.2. May Vs December Fishery

The original intention of the MFPO had been to prosecute a fishery within the FMZ in May 2013; however, following advice from Bangor University and DEFA the decision was taken to defer the fishery until December. In May processors on the Isle of Man were paying in the region of £9.50 per kg of meat weight (pers. comms. Isle of Man Seafood Products Ltd.), compared with the £13.50 realised by the December fishery. Considering approximately 4743kg meat weight of scallops were landed, the increased revenue generated by fishing the area in December was close to £19,000; 42% greater than the same landings would have commanded in May. In addition by deferring the fishing till after spawning each scallop landed would have had the chance to spawn an additional time, thus potentially increasing recruitment to the stock in future years.

2.6.3. Advantages of the Contracting Process

One of the major factors that would have affected profitability, had the MFPO allowed each of its members to fish a personal allocation of bags from within the FMZ, would have been the additional fuel costs of vessels steaming to, and returning from Ramsey Bay. With costs being allocated solely on a per kg shell weight basis, and therefore not taking into account additional factors such as fuel use, it was not possible to directly compare the “three boat” and “all in” scenarios in terms of their economics. However, it is possible to approximate the additional distance that would have been travelled had the “all in” option been taken. The shortest distance from the islands four main ports to the Fishing Zone were calculated (Table 3). Each port was then assigned a weighting. These weightings were based, following

advice from DEFA, on the proportion of vessels in the fleet expected to be based at each particular port (Table 3). The potential cumulative round trip distance, for the total number of vessels (based on a potential fleet of 28), from each port to the Fishing Zone, could then be calculated (Table 3). The total theoretical steaming distance from the “all in” scenario can thus be compared with the total actual steaming distance resulting from the fishery (the “three boat” scenario) (Table 4).

Table 3. Theoretical steaming distances which would have resulted from an “all in” approach to the December 2013 Ramsey Bay fishery. Presented are the shortest distance from each port to the Fishing Zone, the weighting assigned to each port and the total combined one-way and round trip distances (in km) for all vessels from each port.

"all in"	A	B	C = (B x 28)	D = (C x A)	E = (D x 2)
Departure Port	Dist to Fishing Zone (km)	Weighting	Eq no. of boats	Tot Dist to Fishing Zone	Dist Round Trip
Port St. Mary	48	0.165	4.62	222	444
Douglas	25	0.165	4.62	116	232
Peel	41	0.3333	9.33	383	766
Ramsey	5	0.3333	9.33	47	94
Total approximate distance (km)				768	1536

Table 4. Actual steaming distances resulting from the December 2013 fishery in Ramsey Bay FMZ. Presented are the shortest distances from each port to the Fishing Zone, total fishing days for vessels from each port and the total combined one-way and round trip distances (in km) for all vessels from each port.

"three boat"	A	B	C = (A x B)	D = (C x 2)
Departure Port	Dist to Fishing Zone (km)	Total fishing days	Tot Dist to Fishing Zone	Dist Round Trip
Ramsey	5	5	25	50
Douglas	25	1	25	50
Total approximate distance (km)			50	100

In addition the profits resulting from the “all in” scenario would have been earnings from which crew and vessel costs would have had to be paid, rather than a dividend from which deductions had already been made. Finally vessels, other than the three that were involved in the fishery, were free to fish elsewhere while the Ramsey Bay fishery was taking place. Therefore, an “all in” scenario would have concentrated fishing effort on Ramsey Bay and led to a loss of earnings from MFPO members fishing elsewhere around the island while the Ramsey Bay fishery was ongoing. This potential loss of earnings must be taken into account when calculating the profitability of the fishery to individual MFPO members.

2.7. Environmental Impacts of the Fishery

2.7.1. Green House Gas (GHG) emissions

In order to estimate GHG emissions during the Ramsey Bay fishery it was first necessary to quantify fuel use. Fishers were asked to estimate their average speed and fuel consumption when a) fishing and b) steaming. Based on the fuel use per hour for each activity and the known steaming and fishing times, fuel use during the fishery was calculated. Total fuel used during the Ramsey Bay fishery calculated in this manner was approximately 1338L resulting in a fuel intensity (total fuel usage per kg of catch landed), of 0.057L/kg and the emission of 3.6 tonnes of GHGs (Table 5).

Using values calculated in a previous study by Walsh (2010), relating to fuel use and emissions in the Isle of Man king scallop fishery, it is possible to assess the environmental impact of the fishery in Ramsey Bay in the context of the wider Manx king scallop fishery. Had the Manx fleet landed a similar quantity (23400kg) of scallops from elsewhere around the island, based on Walsh’s (2010) fuel intensity value of 0.54L/kg, fuel use and GHG emissions would have been substantially higher (Table 6). In this case total fuel use would have been approximately 12636L and emissions would have been in the region of 34 tonnes with the vast majority, 33 tonnes, being CO₂.

The figures in Walsh (2010) were based on the entire Manx fleet and highly variable island-wide catch rates. Catch rates in Ramsey Bay were higher and steaming distances lower than is generally the case; this resulted in the fishery being more energy efficient than the values calculated in Walsh (2010). It is important to note that in both instances only direct emissions as a result of the burning of fossil fuels are considered. Indirect emissions related

to factors such as boat building and maintenance, secondary processing, and transport of the catch are not included.

Table 5. Calculated fuel use and Green House Gases (GHGs) emissions during the December 2013 fishery in Ramsey Bay FMZ. Values calculated based on fuel use provided by participants. Values are presented in kg CO₂ equivalent.

	Fuel (L)	CO ₂ (kg)	CH ₄ (kg)	N ₂ O (kg)	Total GHGs (kg)
		kg CO ₂	(kg CO ₂ eq)	(kg CO ₂ eq)	(kg CO ₂ eq)
Per kg live weight scallops	0.057	0.15	0.0001	0.0016	0.1536
Total from fishery	1338	3543	2	37	3593

CO₂ = Carbon Dioxide, CH₄ = Methane, N₂O = Nitrous Oxide, GHGs = Green House Gases, tot kg CO₂ = Total kg CO₂ equivalent, CO₂ eq. = the equivalent amount of CO₂ required to produce a similar environmental impact.

Table 6. Fuel use and emissions of Green House Gases (GHGs), based on values calculated in (Walsh, 2010), had similar landings to the Ramsey Bay fishery (23400kg) been attained from the wider Manx king scallop fishery. Values are presented in kg CO₂ equivalent.

	Fuel (L)	CO ₂ (kg)	CH ₄ (kg)	N ₂ O (kg)	Total GHGs (kg)
		kg CO ₂	(kg CO ₂ eq)	(kg CO ₂ eq)	(kg CO ₂ eq)
Per kg live weight scallops	0.54	1.43	0.001	0.015	1.45
Total from fishery	12636	33462	23	351	33930

CO₂ = Carbon Dioxide, CH₄ = Methane, N₂O = Nitrous Oxide, GHGs = Green House Gases, tot kg CO₂ = Total kg CO₂ equivalent, CO₂ eq. = the equivalent amount of CO₂ required to produce a similar environmental impact.

2.7.2. Energy Return on Investment (EROI)

Capture fisheries may be thought of as industrial systems whose primary focus is on the production of food energy. Quantification of their energy efficiency may therefore be extremely useful and this is traditionally done by calculating their edible energy return on investment (EROI) ratio. As the nutritional component of shellfish is primarily a function of their protein content, edible protein energy output is the most appropriate basis for comparison in this instance (Tyedmers *et al.*, 2004). The calculated edible protein Energy Return on Investment (ep-EROI) ratio for Ramsey Bay, based on a fuel usage of 1338L fishery was approximately 0.712 (Table 6). This ratio means that for every kg of chemical energy

expended, in the form of fuel, 712 grams of edible energy, in the form of protein were obtained. In order to compare the efficiency of the Ramsey Bay fishery with normal fishing activity of the Manx king scallop fleet the same calculation was performed using Walsh's (2010) fuel use statistics for the fishery as a whole. The result was a drop in the EROI ratio to 0.075, or 75g of protein per 1kg of fuel (Table 7), implying the Ramsey Bay fishery was substantially more energy efficient.

As well as comparing extremely favourably with the wider Isle of Man scallop fishery this ep-EROI ratio of 0.712 for Ramsey Bay scallops compares well with corresponding values of 0.056, 0.038, 0.025 and 0.019 for pork, eggs, farmed Atlantic salmon and feedlot beef respectively (Tyedmers, 2004).

Table 6. Values used to calculate edible protein Energy Return On Investment (ep-EROI) ratio of scallops from the Ramsey Bay fishery.

A	Total kg landed	23389
B	Average meat yield	20.24%
C = A x B	Total meat yield	4734
D	Protein content scallops ⁽¹⁾	16.70%
E = C x D	Edible protein from fishery (kg)	791
F	Fuel use litres	1338
G	Specific gravity diesel	0.83
H = F x G	Fuel use kg	1111
I = E / H	ep-EROI	0.712

(1) Mason (1959).

Table 7. Values used to calculate edible protein Energy Return On Investment (ep-EROI) ratio from the wider Manx king scallop fishery based on values presented in Walsh (2010).

A	Total kg landed	23389
B	Average meat yield	20.24%
C = A x B	Total meat yield	4734
D	Protein content scallops	16.70%
E = C x D	Edible protein from fishery (kg)	791
F	Fuel use litres	12630
G	Specific gravity diesel	0.83
H = F x G	Fuel use kg	10483
I = E / H	ep-EROI	0.075

3. Discussion

3.1. Area affected

While the actual area affected would appear small it is essential to take into account the fact that the Fishing Zone represents the area within the FMZ where surveys showed the greatest abundances of scallops (Appendix 3). Considering that the highest densities of scallops were present within the Fishing Zone this would imply that the Fishing Zone is also the optimal area, in terms of habitat suitability, for scallops. Therefore the area of greatest suitability for scallops was disproportionately affected by the fishery when compared with the FMZ as a whole. However, given the relatively small area affected by the fishery, the MFPO, by their considerate and conservative approach to this year's fishery, minimised the potential impact on the FMZ as a whole and likely maintained the ecological integrity of the area as stipulated under the conditions of their lease.

3.2. Size and Age Frequencies

When compared to the island-wide average Ramsey Bay exhibited a lower percentage contribution of older individuals to the population structure (Figure 4). This could be due to the fact that stocks were fished down to a critical level before the closure and thus very few pre-2009 individuals remain. Within Ramsey Bay the relative absence, compared with the island-wide average, of individuals in the year 5 age class could potentially be a consequence of poor localised recruitment immediately following the closure (Figure 4). One reason behind this lack of localised recruitment could be that scallops (being sessile) were not present in sufficient densities to recruit effectively, a phenomenon known as density dependent recruitment (Claereboudt, 1999). Scallop stocks within Ramsey Bay have been shown to rely, at least in part, on self-recruitment, with particle tracking experiments showing the retention of a high proportion of spat released within the Bay (Neill and Kaiser, 2008). In addition, fishing vessels are by their very design poor catchers of undersized individuals and tend to underestimate the presence of smaller individuals (Murray *et al.*, 2013). This underestimation is logical when it is considered that fishing gear is designed so as not to retain undersized individuals. Aside from the ecological benefits incurred, the non-capture of undersized individuals has additional economic advantages associated with reduced sorting and handling time of catch. Additional issues arising from a lack of juveniles

in the catch include the potential for the accuracy of resulting growth curves to be affected and a difficulty in predicting future recruitment to the stock. A number of tows with queen scallop dredges conducted in parallel to the main fishery might go some way to filling in this gap in the dataset.

3.3. Catch Depletion Rate

The results of modelling showed a decline in CPUE across the fishery, as one would expect, related to a decreased biomass of scallops available for capture (Figure 6). While the decline in CPUE may appear from Figure 6 to be slight, it is essential that other factors are considered in the interpretation of results. Consistently high CPUE does not necessarily infer high overall scallop abundances. An issue with using CPUE to estimate abundance arises from the fact that the two often do not exhibit a linear relationship (Branch et al., 2006). This non-linear relationship is often particularly evident in fisheries targeting species which are present in dense aggregations, such as scallop beds, where decreases in abundance may be masked by consistently high CPUEs, a phenomenon known as hyperstability (Harley et al., 2001). A major danger associated with hyperstability is the potential for the creation of a positive feedback loop whereby spawning stock densities, a factor critical to the reproductive success of sedentary species such as scallops (Stokesbury and Himmelman, 1993; Claereboudt, 1999), decline as a result of the removal of adults, leading to poor spawning events, poor recruitment and in turn further reductions in abundances. Indeed hyperstability is thought to have been a major contributing factor in the collapse of the Newfoundland cod fishery (Rose and Kulka, 1999).

While the most likely agent masking a decline in overall abundance in this case would be the fishers' ability to move within the Fishing Zone, additional contributing factors could have included learning behaviour of fishers' or changing weather conditions, both of which have in the past been shown to effect CPUE (Murray et al., 2011; Xiao, 2004). Learning behaviour refers to the fishers' increasing knowledge of the conditions in the area, leading to the optimisation of gear setups and increased catch efficiency.

While in this particular instance scallops densities may not have come close to approaching critical levels there is still a large degree of uncertainty. It is vital that in the future care is taken to ensure that the FMZ does not return to the 2009 levels whereby stocks would

again take several years to recover. In addition it is critical to bear in mind that CPUEs in the Fishing Zone may not be representative of the entire FMZ. In fact if one takes into account the results of the preliminary study (Appendix 3) the converse is most likely the case, whereby if the fishery were to be extended to the entire FMZ then a significant reduction in overall CPUE would be expected.

3.3. Economics

After all costs had been deducted the fishery realised a net profit of circa £300 per hectare. This per hectare return would appear to compare favourably with many more traditional land based protein production methods; however, more work needs to be done in this area. In comparing the yields from a hectare of arable land versus a hectare of seabed one must take into account the fact that, when harvested, close to 100% of biomass is removed from arable land; there is unlikely ever to be this level of biomass removed from the seabed. In addition arable land is seeded annually, while seeding of scallop beds is a lesser known phenomenon. Some seeding of scallops, both formal and informal, did take place in Ramsey Bay immediately following the closure, with 100,000 scallops being released in the south of the Bay (DEFA, 2010). Follow up studies were not conducted and as such the effects are uncertain. Generally in fisheries production occurs naturally, therefore it is vital that a critical biomass of spat producing adults is maintained in order for the “crop” to be continually harvestable year on year. Finally, arable farms may produce two crops in a single year thereby effectively doubling their annual yield whereas the fishery in Ramsey Bay at present has not been proven sustainable and can only be viewed as a single harvesting event.

3.3.1. May Versus December Fishery

With a price difference of approximately £4 the economic advantages of fishing the Bay in December rather than May are obvious. Perhaps less obvious are the ecological advantages conferred by the presence of high densities of spawning stock for the autumn spawning event, which should increase the likelihood of strong recruitment in the future.

3.3.2. Advantages of the contracting process

Aside from the obvious advantages of reduced fuel costs as a result of less cumulative steaming time the cooperative “three boat” scenario has numerous other advantages over

the “all in” scenario. These include easier monitoring and enforcement of the fishery, a reduced negative impact on public opinion than would be expected from having all the MFPOs boats in the area at the same time and reduced interference competition between fishing vessels. The cooperative “three boat” scenario, albeit not necessarily restricted to 3 boats, is therefore a much more desirable option going forward than a return to open fishing.

3.4. Environmental Impacts and EROI

Tyedmers et al., (2005) found that approximately 1.2% of global oil consumption is taken up by fisheries, resulting in greenhouse gas emissions in excess of 130 million tonnes of CO₂. The Ramsey Bay fishery was as a result of its high capture rate, the extremely short steaming distances involved and the lack of interference competition between vessels, much more energy efficient than the Isle of Man scallop fishery as a whole. In fact comparisons between the fuel intensities, total fuel usage per kg of catch landed, of the Ramsey Bay fishery (0.057L/kg) and normal scalloping activity by the Manx fleet (0.54L/kg) (Walsh, 2010) show that the Ramsey Bay fishery was up to nine times more energy efficient. Accompanying this increase in efficiency was a proportional reduction in the emission of GHGs (Table a, Table 5b and Table 6).

3.5. Video Sled Survey

The original intention this year had been to conduct a Before After Control Impact (BACI) experiment using a camera sled in the Fishing Zone with the aim of quantifying fishing impacts and recovery. Unfortunately, due to inclement weather, visibility in the Bay was not of sufficient quality for the survey to be completed successfully. It is crucial therefore that prior to the area being opened in the future a thorough survey is completed in order to establish baseline conditions in the area.

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5. Appendix

Appendix 1. Estimating CPUE during the December 2013 fishery in Ramsey Bay FMZ.

In order to investigate whether catch rates were depleting as the fishery progressed CPUEs were compared through the use of Generalised Additive Models in R; modeling was conducted with the 'mgcv' package (Wood and Augustin, 2002; Wood, 2006) and data from all tows in the fishery for which complete GPS records were available. Three candidate models were identified and tested:

(Model 1) $CPUE_{GPS} \sim te(\text{average easting, average northing, tow order}) + \text{vessel}$

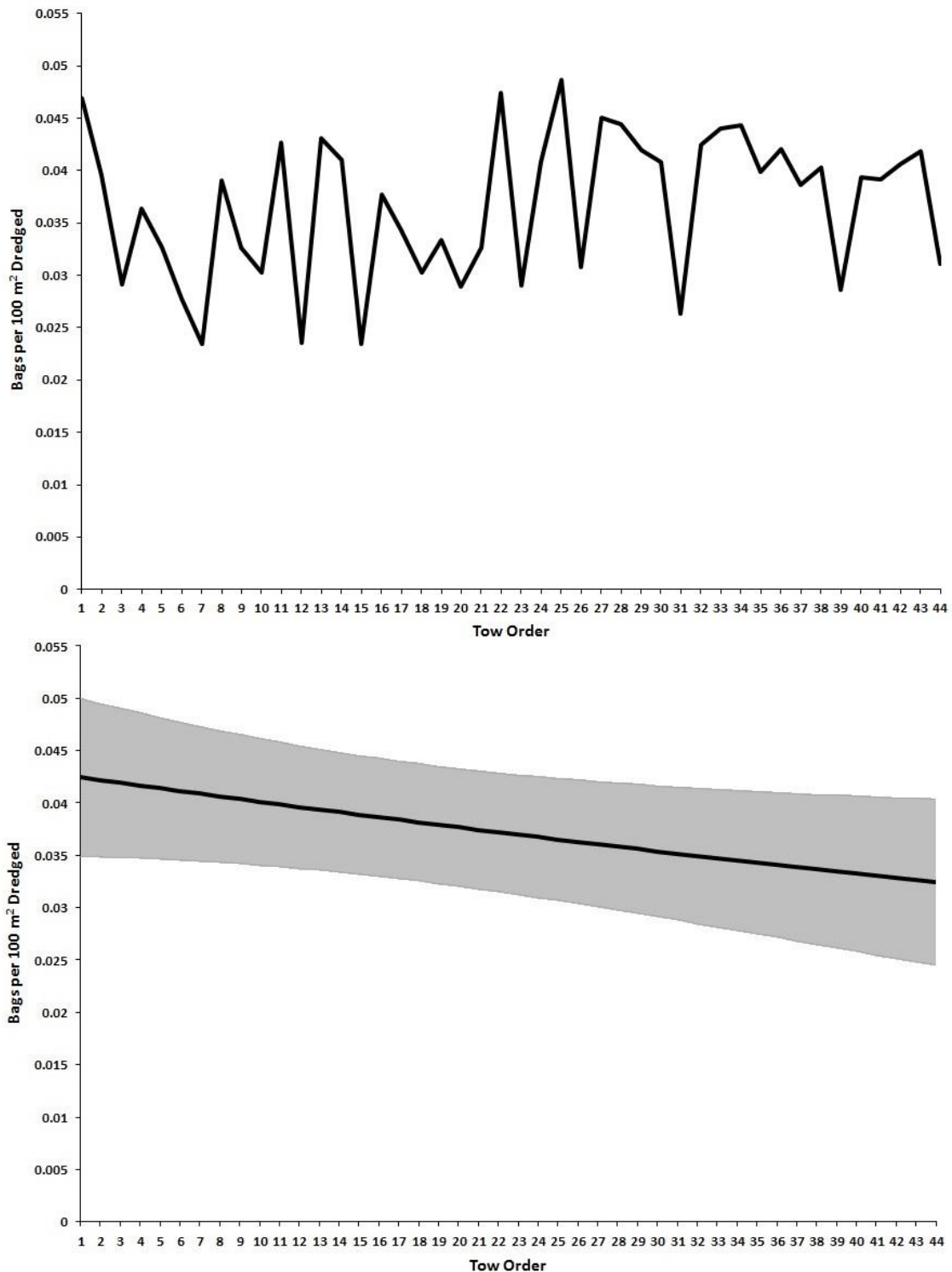
(Model 2) $CPUE_{GPS} \sim s(\text{average easting, average northing}) + s(\text{tow order}) + \text{vessel}$

(Model 3) $CPUE_{GPS} \sim te(\text{average easting, tow order}) + \text{vessel}$

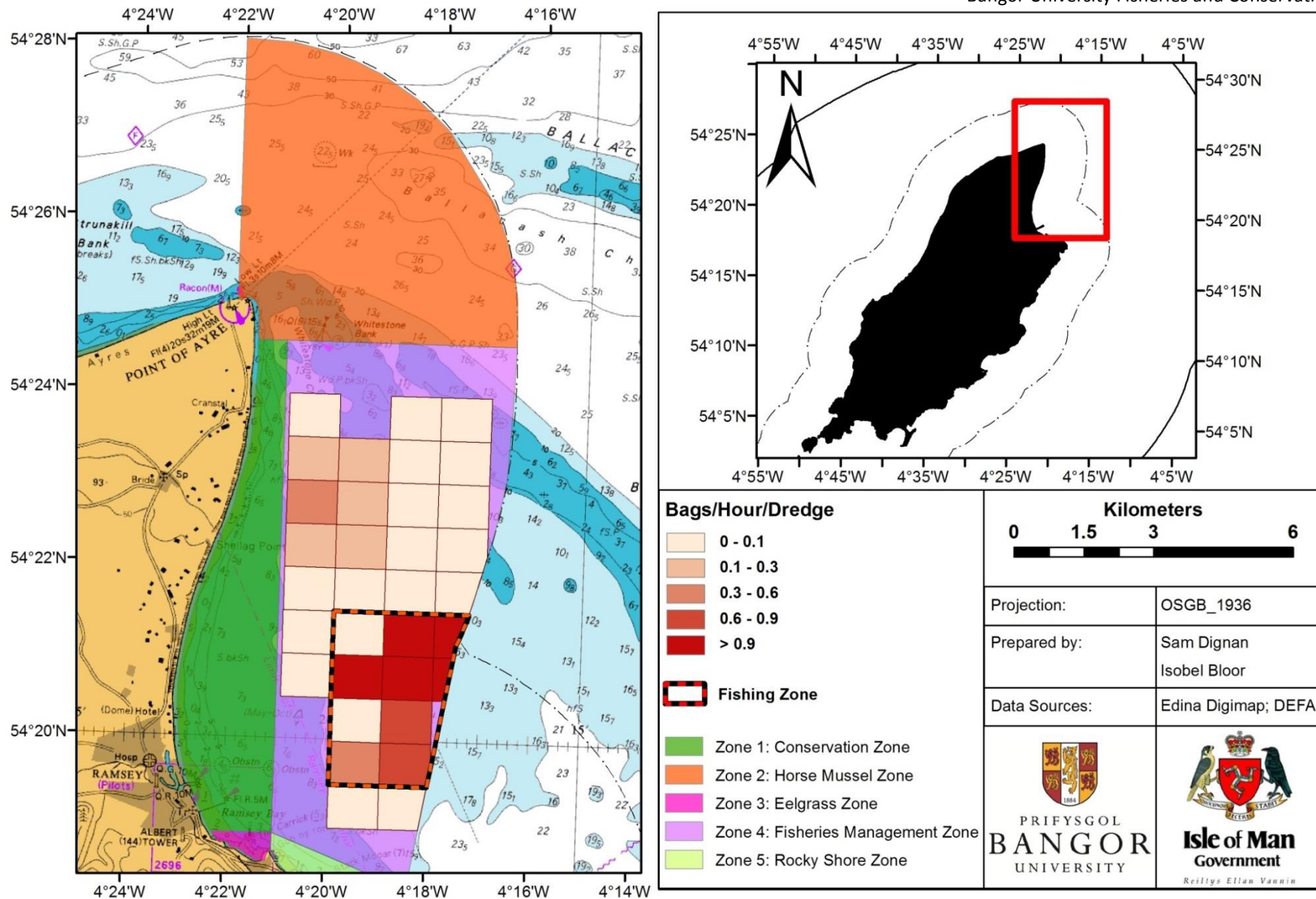
Where, $CPUE_{GPS}$ = Catch per Unit Effort calculated from GPS logger and vessel log sheet data, average easting = the average easting for the each individual tow, average northing = the average northing for each individual tow, tow order = the tows order in the fishery based on its start time and vessel = a unique vessel identifier; 's' and 'te' denote isotropic and tensor product smooths respectively with 'te' used where the scales of the interacting coefficients differed, i.e. position and tow order. Models were fitted using a gamma error distribution and a log link. In addition the degrees of freedom in Model 1 had to be restricted in order to overcome the limited amount of data available.

Three Generalised Additive Models were conducted with the response variable CPUE of scallops. Model 1 (deviance explained = 64.6%) explained significantly more deviance than Model 2 (deviance explained = 49.8%) (ANOVA, $F = 3.1$, $p = 0.025$) and Model 3 (deviance explained = 52.1%) (ANOVA, $F = 2.73$, $p = 0.043$) and had a lower Akaike Information Criterion (AIC) score (-331.28 compared to -324.5 and -326.2 respectively); as a result CPUE was predicted using Model 3. When Model 1 was fitted to the data 64.6% of deviance was explained and a significant effect of the interaction between average easting, average northing and tow order exhibited ($p < 0.01$). While vessel effect was not shown to be significant its removal substantially reduced the deviance explained, to 56%, and increased AIC, to -328.8. Additionally, there was an obvious observed difference in catch rate between vessels in the fishery. Taking both these factors into account it was felt that leaving vessel as

a coefficient in the model would be more appropriate in this instance. The model showed that CPUE decreased slightly across the duration of the fishery (Appendix 2).



Appendix 2. CPUE, in bags per 100m² dredged, during each tow of the December 2013 fishery in Ramsey Bay FMZ based on non-standardised data (top) and data standardised to remove position and vessel effects (bottom). Shaded area indicates ±2 standard errors (Note there is no standard error on the unstandardised data as it relates to individual tows).



Appendix 3. Results of initial Ramsey Bay FMZ survey September 2013, conducted aboard the FPV Barrule. Densities are presented in bags per dredge per hour. Fishing Zone was outlined based on the areas of greatest scallop density.

