



## **Boom not bust: Cooperative management as a mechanism for improving the commercial efficiency and environmental outcomes of regional scallop fisheries**

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1   **Title:** Boom not bust: Cooperative management as a mechanism for improving the commercial  
2   efficiency and environmental outcomes of regional scallop fisheries

3

4   **Abstract**

5   The environmental impacts of food production are increasingly influencing consumer's food choices.  
6   To maintain market access in this context, the fishing industry must adopt strategies and technologies  
7   that reduce their carbon emissions, environmental footprint, bycatch and seabed impact. In this study,  
8   closure of a depleted scallop fishing ground, to enable stock recovery, coupled with a transition to a  
9   cooperative management system, based on territorial user rights, promoted fishers to make  
10   management decisions that have improved the environmental outcomes and economic efficiency of  
11   this fishery. Innovative cooperative management systems like territorial user rights that decentralise  
12   decision making and provide users rights to a defined fishing area, could help mitigate against the  
13   negative impacts and issues traditionally associated with scallop dredge fisheries, and help maintain  
14   both stock biomass and consumer demand in a market increasingly dominated by sustainably certified  
15   food products.

16   **Key words:** Scallops, TURFs, GHG Emissions, LPUE

17

18   **1. Introduction**

19   Bottom-towed fisheries account for 25% of global seafood landings. Of these, scallop (Pectinid)  
20   fisheries make an important contribution with 632,000 t landed, worth \$US 1,579 million in 2017 (FAO  
21   2018, 2019). Despite their economic and food security relevance, many scallop fisheries lack the  
22   robust management regimes required to regulate effort and landings (Stewart & Beukers-Stewart,  
23   2009), and this is especially true of most European scallop fisheries as they are not an EU-regulated  
24   quota species. In the absence of biologically referenced fishing effort and harvest limits the habitat  
25   specificity and sessile nature of scallops makes them vulnerable to over fishing (Stewart & Howarth  
26   2016) and can result in significant decreases in catching efficiency and profitability (e.g. reported  
27   reduction in landings per unit effort in the United Kingdom, Curtis et al. 2017).

28

29   The environmental impacts of scallop dredge fisheries on the seabed are well documented and result  
30   in reduced habitat complexity, habitat fragmentation, loss of biodiversity and reduced ecosystem  
31   functioning of marine seabed habitats (e.g. Thrush & Dayton 2002; Kaiser et al. 2006; Hiddink et al.,  
32   2017). The nature and extent of these impacts are dependent on the physical characteristics of the  
33   seabed, the specific gear type, and the composition of the benthic communities (e.g. Collie et al. 2000;  
34   Bradshaw et al. 2001; Thrush & Dayton 2002; Kaiser et al. 2006; Hughes et al. 2014; Hiddink et al.  
35   2017). Hiddink et al. (2017) estimated that bottom-towed fishing gears remove 6 – 41 % of faunal  
36   biomass per pass with average post-trawl recovery times of 1.9 – 6.4 years, depending on the fishery  
37   and environmental context. As scallop fisheries increase fishing intensity, this will correspondingly  
38   increase their ecological 'footprint' on the seabed and the recovery period for seabed biota in relation  
39   to the frequency of past trawling impacts and the recovery rates of the biota present (Lambert et al.  
40   2011, 2017; Hiddink et al. 2017; Kaiser et al. 2018). Furthermore, future scallop spat settlement and  
41   recruitment success may be linked to the presence of benthic biota that act as settlement substrata,  
42   thus the fishery has the potential to significantly limit its own long-term sustainability if the impact of  
43   benthic biomass removal is not managed appropriately (Lambert et al. 2011).

44

45 Direct impacts on the seabed are not the only concern associated with declining productivity of scallop  
46 fisheries. Commercial fisheries, which rely heavily on the use of fossil fuels, are known to be a  
47 significant contributor to global CO<sub>2</sub> emissions (e.g. Greer et al. 2019; Parker & Tyedmers, 2015; Parker  
48 et al. 2018; Tyedmers, 2004) equating to 2-3% of the total emissions from global food production in  
49 2016; Mbow et al. 2019). Inefficient fishing practices (for example scallop vessels targeting low density  
50 scallop beds) leads to greater average CO<sub>2</sub> emissions per tonne of target-species landed. This is an  
51 emerging pattern which has developed in recent years in commercial fishing across the globe (e.g.  
52 Parker et al. 2018). As with other food production industries, commercial fisheries are required to take  
53 action to reduce Greenhouse Gas (GHG) emissions following the ratification of the Paris Agreement in  
54 2015, which aims to keep global warming optimally under 1.5 °C (UNFCCC, 2015; Rogelj et al. 2016).  
55 This is particularly relevant to scallop dredge fisheries that already have a poor public perception for  
56 environmental impacts. Since fuel is a major expense in fishing industry business models (e.g. Parker  
57 & Tyedmers, 2015), as well as CO<sub>2</sub> emissions from fuel use representing a major externalised cost to  
58 the environment, lower carbon fisheries represent a motivating win-win opportunity for commercial  
59 fisheries (Greer et al. 2019).

60 Globally, the centralised top-down governance of fisheries and conventional input controls have  
61 proven inadequate in resolving many issues associated with modern exploitation of fisheries resources  
62 (e.g. Pauly et al. 2003; Grafton et al. 2006), particularly on a local scale. Without robust limits on  
63 access, effort or the allocation of individual rights to the fishery resource or area, fishers are  
64 incentivised to compete in a short-term ‘race to fish’ (e.g. Tragedy of the commons; Hardin 1968)  
65 rather than investing in protecting species and habitats for longer-term sustainability (e.g. Berkes et  
66 al. 2001) and reducing wider environmental impacts, such as GHG emissions. By contrast, bottom-up  
67 decentralised or co-management governance systems, where management decisions are delegated  
68 to local communities or fishers’ organisations (e.g. Berkes et al. 2001, Lubchenko et al. 2016), seem to  
69 be proving their effectiveness as fishery management tools, especially for sessile or sedentary species  
70 (Gelcich et al. 2012; Nguyen et al. 2017). This includes the use of rights-based management systems  
71 that can promote incentives for fishers to protect and invest in the resource. Examples of such systems  
72 include Individual Quotas (IQs) or Individual Transferable Quotas (ITQs), which provide licenced  
73 individuals with a share of the total allowable catch (TAC), and Territorial User Rights Fisheries (TURFs),  
74 which provides user rights within a defined fishing area.

75  
76 Territorial user rights fisheries (TURFs) are a form of rights-based management (RBM) system that is  
77 decentralised and allows for a more complete conveyance of property/resource rights to members by  
78 defining harvesting access within a defined fishing area. Self-governing associations or organisations  
79 are usually established for TURFs with the role of managing and protecting the resources within the  
80 fishing area, deciding on allocation of resources to its members and ensuring compliance with  
81 regulations (Liu and Qin, 2018). A TURF can therefore provide a suitable context for fishers to adopt  
82 management measures that promote economic and harvesting efficiency, encompass ecosystem  
83 based management (EBM) and enhance economic viability through stock security, whilst  
84 simultaneously eliminating the ‘race to fish’ found in many open-access fisheries (e.g. Berkes et al.  
85 2001). For scallop dredge fisheries, a move towards TURFs may incentivise fishing behaviours that  
86 consider the wider ecosystem and fleet economic efficiency, which is timely given the current  
87 increasing economic and environmental concerns related to scallop fisheries. This type of rights-based

88 cooperative approach has been previously conceptualised for the Atlantic Sea Scallop fishery as a  
89 means of incentivising rational and sustainable management (Baskaran and Anderson, 2005).

90

91 Territorial user rights fisheries (TURFs) are the focus of this paper, which quantitatively evaluated the  
92 performance of a fishery management experiment within the *Pecten maximus* scallop fishery of the  
93 Isle of Man (Irish Sea). This opportunity arose when one of the fishing grounds within the wider scallop  
94 fishery had been fished to commercially unviable levels under the *status quo* management system.  
95 This ground was closed for three seasons to enable stock recovery, and then re-opened as a TURF  
96 located within a multi-zoned marine protected area (MPA). Both the TURF and the remaining fishing  
97 grounds within the RCA fishery were monitored for a range of performance indicators including  
98 commercial (i.e. landings per unit effort; LPUE) and environmental (i.e. greenhouse gas (GHG)  
99 emissions and area of seabed impacted per tonne of live shell weight (LSW) of scallops landed). In this  
100 way we assessed to what extent the TURF had improved the environmental and economic efficiency  
101 of scallop dredge fishing.

102

## 103 **2. Methods**

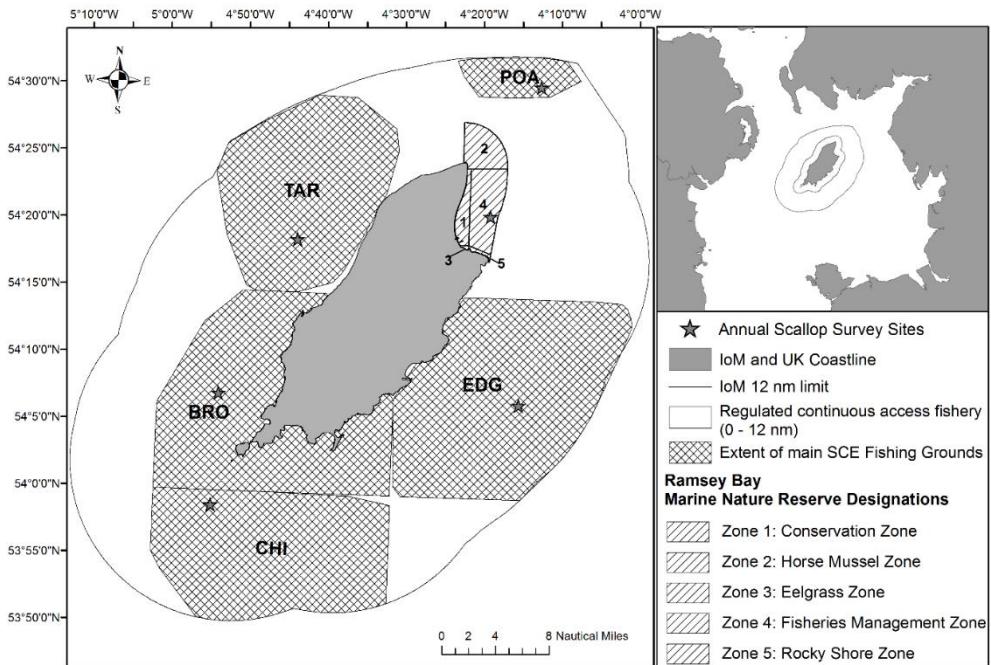
### 104 **2.1 Fishery**

105 The Isle of Man (IoM) is situated in the northern Irish Sea (ICES Statistical Areas VIIa). A dredge fishery  
106 for king scallops operates within the IoM's territorial sea (TS) (0-12 M;  $\approx 3998 \text{ km}^2$ ) with six distinct  
107 king scallop fishing grounds ranging in depth from 10 – 95m (Figure 1). Individual grounds represent  
108 permanent scallop beds that are known to recruit annually and are delineated as discrete fishing areas  
109 determined from historical spatial fishing activity and habitat discrimination. All grounds within the TS  
110 have typically been considered as a single management unit.

111

112 The main king scallop fishery is permitted under licence within the 12 M territorial limit with gear and  
113 quota restrictions, a minimum landing size (MLS) and temporal restrictions used for finer-scale  
114 management (Table 1); this *status quo* management system will be referred to hereafter as Regulated  
115 Continuous Access (RCA). The Isle of Man Government has sole jurisdiction for fisheries management  
116 within the 0 – 3 nm territorial limit (Figure 1), which provided the necessary legal flexibility to trial co-  
117 management of a rights-based inshore fisheries within Ramsey Bay (RAM), which falls entirely within  
118 the 0-3 nm limit. This novel management system will be referred to hereafter as the territorial user  
119 rights fishery (TURF).

120



121

122 *Figure 1: The Isle of Man is situated in the Irish Sea between Ireland and the United Kingdom. Ramsey Bay Marine Nature*  
 123 *Reserve (MNR) is situated off the north-east coast of the island. The MNR consists of five zones with different levels of*  
 124 *protection. The Fisheries Management Zone (Zone 4; FMZ) has relatively low protection and is managed under a fisheries*  
 125 *agreement. The Ramsey Bay fishery occurs exclusively within the FMZ and is delineated from the RCA fishery by the MNR*  
 126 *boundary. The outer extents of the five main fished grounds from within the RCA fishery (0 – 12 nm) that are used for*  
 127 *comparison are indicated on the map by the hatched areas. CHI: Chickens in the south; BRO (BRA): Bradda in the south/south-*  
 128 *west; TAR: Targets in the west; POA: Point of Ayre in the north and EDG: East Douglas in the east. Eleven historic annual*  
 129 *scallop survey stations were established in 1992 with one located in each of the six main king scallop fishing grounds, grey*  
 130 *stars indicate the location of these survey stations.*

131 *Table 1: Management measures and restrictions associated with the RCA king scallop fishery in the Isle of Man territorial*  
 132 *sea.*

Management Measure	Specification
Open season	1 <sup>st</sup> November to 31 <sup>st</sup> May
Engine power	≤ 221 kW (or grandfather rights)
Dredge width	25 feet (7.62 m) in 0-3 M 35 feet (1.067 m) in 3-12 M
Minimum landing size	110 mm
Daily curfew	18:00 – 06:00
Closed areas	Permanent and Temporary
Total allowable catch	2017/2018 season onwards (variable annually)
Number of 0-12 nm licences	94 as of 2016/2017

133

134 Ramsey Bay (RAM), which was historically a productive fishing ground and is likely to be self-recruiting,  
 135 was closed to fishing in December 2009 for three fishing seasons to enable stock recovery following a

136 period of intense overfishing. In October 2011 RAM was designated as a marine nature reserve (MNR),  
137 with five zones covering an area of 94.5 km<sup>2</sup> (Figure 1) protecting priority habitats including horse  
138 mussel reef and maerl beds. The MNR also forms one of the core zones of the UNESCO Biosphere Isle  
139 of Man. Whilst four of the zones were closed to mobile fishing gear, a fifth zone was designated a  
140 fisheries management zone (FMZ) (47.5 km<sup>2</sup>) under a TURF management system. The TURF provided  
141 user rights to a limited group of local fishers to harvest king scallops from the area. Eligible participants  
142 had to be members of the Manx Fish Producers Organisation (MFPO) and hold an active scallop  
143 entitlement for the RCA fishery. The number of TURF fishers gradually increased from 27 to 33 over  
144 the study period. During the closure period RAM was monitored with annual scientific surveys to  
145 monitor stock recovery and by 2013 it was considered to have increased to commercially viable levels.  
146 Ramsey Bay was then opened as a TURF under an initial five-year agreement (2013 – 2018), which has  
147 since been extended. Users were given responsibility for strategic decisions on where, when and how  
148 much to fish, whilst ensuring that the ‘ecological integrity’ of the area was maintained. Although not  
149 formally defined, ecological integrity has been assessed via regular habitat monitoring and by the size  
150 and age structure of the scallop stock within the FMZ. Enforcement within the TURF was primarily  
151 overseen and administered by its members but with Government support should legal proceedings  
152 be required. All fishers involved in the TURF also had access to the wider RCA fishery as well.

153

154 The establishment of a TURF for fishermen belonging to the MFPO provided the basis and security of  
155 tenure required to introduce positive management measures for sustainable fishing, including: limited  
156 harvest (TAC) and effort; a limited fishing season to promote habitat recovery (i.e. 1 – 3 week fishery  
157 in Ramsey Bay); timing the fishery to achieve maximum profitability (opening around the more  
158 valuable Christmas period); cooperative fishing (i.e. reducing the number of individual vessels fishing  
159 and the distance steamed) and pre-fishery surveys to enable fishing to be targeted on high-density  
160 areas while allowing lower-density areas to remain unfished for recovery. The latter strategy increases  
161 harvesting efficiency and lowers fuel use and gear impacts on the seabed. The TURF has also provided  
162 the context for members to limit harvesting so that the scallop population (size and age) structure is  
163 maintained, providing a buffer against recruitment failure in a single year and creating the basis for a  
164 longer-term sustainability of the fishery. The spatial extent and location of the fishable area and total  
165 allowable catch (TAC) within the FMZ is calculated on the basis of stock biomass, which in turn is based  
166 on a detailed annual survey carried out by the MFPO, funded by a single TURF-share retained and  
167 administered by the MFPO itself. This is in direct contrast to the recruit-driven ‘boom and bust’ fishery  
168 that existed in Ramsey Bay prior to the closure in 2009, and essentially still exists in the wider RCA  
169 fishery. From an economic perspective, restricted access to Ramsey Bay negates the general ‘race to  
170 fish’ attitude and empowers fishers to make more rational, longer-term decisions that focus on  
171 increasing harvesting efficiency and economic benefits, and maintaining relatively high stock levels,  
172 rather than harvesting all available resources as quickly as possible in a ‘tragedy of the commons’  
173 approach. This enables the fishery to be maintained at high density and catch rates (boom) but with  
174 sustainable levels of effort (i.e. reduced relative to current RCA levels) so as not to cause significant  
175 intra or inter-seasonal depletion (bust).

176

177 **2.1 Data collection**

178 Since 1<sup>st</sup> November 2006 all scallop vessels fishing in the Isle of Man must have a working vessel  
179 monitoring system (VMS) collecting positional and instantaneous vessel speed at specified time  
180 intervals. Vessels are also required to submit a European Union (EU) logbook record for each fishing  
181 activity detailing the landed weight (kg) and value (£) per species. Since 2017 scallop vessels fishing  
182 within the Isle of Man must also submit a Daily Catch Return (DCR) with information on the trip  
183 landings (kg), fishing location (fished ground), time fished (mins) and gear (number of dredges).

184 The reporting of Landings per Unit Effort (LPUE) for the Isle of Man RCA and Ramsey Bay TURF has  
185 evolved over time and were calculated from Port Erin Marine Laboratory (PEML) logbooks (1983 –  
186 2009); Department of Environment, Food and Agriculture (DEFA) paper logbook records (2007 –  
187 2010); European Union (EU) electronic logbooks (2011 – 2017); DEFA Ramsey Bay Catch Returns (2013  
188 – 2017) and DEFA Daily Catch Returns (2017/2018). Whilst all DEFA and PEML logbooks and returns  
189 contain information on hours fished, EU electronic logbooks only report hours at sea and so hours  
190 fished were estimated from hours at sea, taking into account typical steaming times and fishing  
191 practices based on the observations from vessel monitoring system data (= hrs at sea \*0.85).

192 For consistency, as Ramsey Bay can only be targeted by Isle of Man vessels under 15.7 m length overall,  
193 the data used for analysis in this study was first filtered to include only those trips where Isle of Man  
194 vessels under 15.7 m were targeting king scallops to ensure comparability between data sets.

195

## 196 **2.2 Analytical methods**

197 **2.1.1 Fisheries-dependent indicators**

198 Landings per Unit Effort (LPUE) were calculated, as per standard methods, and are expressed in three  
199 standardised units dependent on the resolution and variables available for datasets from each time  
200 series. LPUE was standardised to scallops per metre of dredge per hour fished (SCE/mDr/hrF) for the  
201 long-term time series (1983 – 2019) for comparability with historical values; to tonnes per hour fished  
202 (t HrF) for recent seasonal trends (2013-2019); and kg per dredge per hour fished (kg/Dr/hrF) for the  
203 most recent fishing season (2017/2018).

204 Fuel efficiency of Manx dredgers was calculated using logbooks and statistics on fuel consumption.  
205 Estimated fuel use (litres) was calculated as 22 litres per hour during fishing and 20 litres per hour  
206 during steaming activities using values collated from studies by Walsh (2010) and Dignan et al., (2014).

207

208 Fuel intensity ( $\text{L t}^{-1}$ ) reports the litres of fuel used by a vessel to land a tonne of live shell weight (LSW)  
209 scallops and was estimated from the Manx fuel-use data noted above, combined with information  
210 from logbooks on the quantity of scallops landed (t) per trip. A density of 0.86 kg/L was used to convert  
211 fuel data from litres to kilograms (Xu et al. 2013) for calculation of fuel coefficients for comparability  
212 to other fisheries (i.e. kg fuel / kg fish).

213

214 **2.1.1 Environmental indicators**

215 GHG emissions were estimated for the fishery using information on average speed (derived from  
216 satellite-based VMS data) and fuel consumption during different activities (split into steaming and  
217 fishing components). Emissions of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O were estimated using the standard approach of  
218 the IPCC Tier 1 method (IPCC 2006) by multiplying the amount of fuel consumed by an appropriate  
219 emissions factor (i.e. CO<sub>2</sub> equivalent [CO<sub>2</sub>e] emissions factor of 2.67620 kg per litre of combusted  
220 diesel). GHG emissions (kg of CO<sub>2</sub>e per kg of LSW) were calculated as:

221             $GHG\ emissions(kg\ of\ CO_2e\ per\ kg\ of\ LSW) = FI\ (l\ per\ kg\ LSW) * 2.67620$

222  
 223        The amount of seabed impacted by fishing gear for both the RCA and TURF fisheries (i.e. km<sup>2</sup> impacted  
 224        per tonne of LSW of scallops landed) was calculated for the 2017/2018 fishing season for each fished  
 225        ground.

226             $km^2\ impacted\ per\ tonne\ of\ live\ shell\ weight = \frac{km^2\ impacted\ per\ trip}{tonne\ of\ live\ shell\ weight\ per\ trip}$

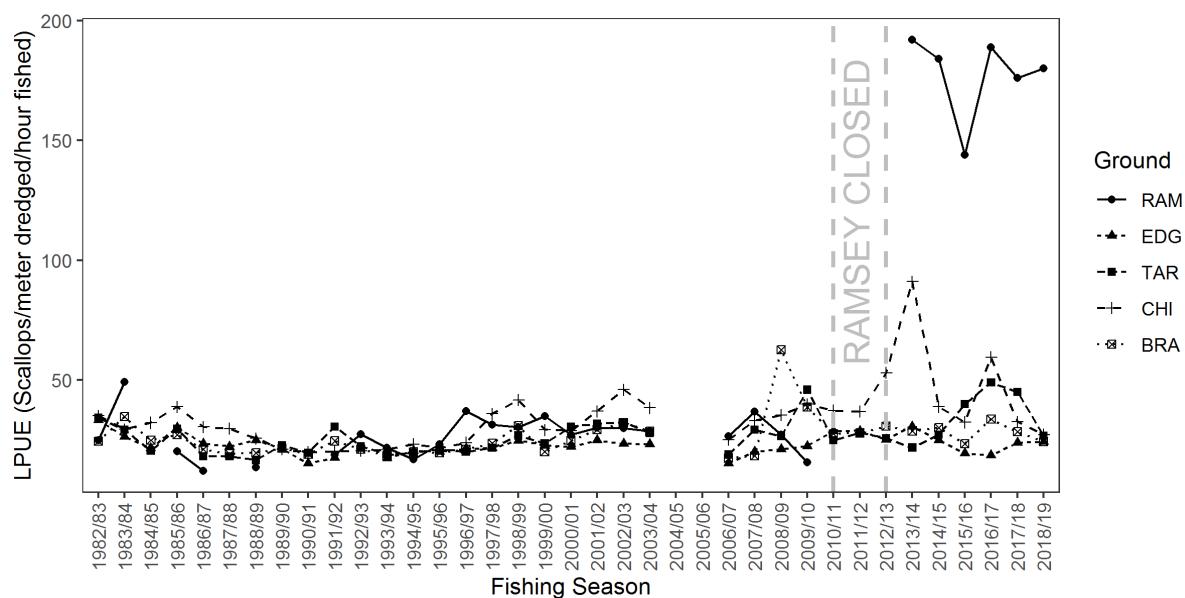
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 228

### 229        3. Results

#### 230        3.1: Long-term annual LPUE trends (1982 to 2019)

231        Historical data (1982 – 2019) on LPUE standardised to scallops (SCE) per metre dredged per hour  
 232        fished (SCE/Dr m<sup>-1</sup>/HrF) indicated that prior to December 2009, when RAM was closed, the average  
 233        annual LPUE for king scallops over the 5 main fished grounds (POA not included here due to limited  
 234        data) ranged from 12 to 49 SCE/Dr m<sup>-1</sup>/HrF (1982/1983 – 2009/2010; Figure 2). Following the closure  
 235        of RAM for three seasons the average annual LPUE for RAM had increased by an order of magnitude  
 236        in 2013 compared to pre-closure values (12 and 192 SCE/Dr m<sup>-1</sup>/HrF in 2009 and 2013 respectively;  
 237        Figure 2). Between 2013 and 2019 the annual average LPUE for RAM ranged from 144 to 192 SCE/Dr  
 238        m<sup>-1</sup>/HrF whilst the four RCA grounds ranged from 18 to 91 SCE/Dr m<sup>-1</sup>/HrF over the same period (Figure  
 239        2).

240



241

242        Figure 2: LPUE (Landings per Unit Effort) standardised to scallops per dredge metre per hour fished for each of the main fished  
 243        grounds (Ramsey Bay = RAM; East of Douglas = EDG, Targets = TAR, Chickens = CHI, Bradda = BRA). It should be noted that  
 244        prior to 2009 all grounds were part of the RCA fishery. A fishing closure was in place In Ramsey Bay for three full fishing  
 245        seasons (2010/2011, 2011/2012 and 2012/2013: indicated by vertical dashed grey lines) to allow scallop stocks to recover  
 246        following depletion. On recovery Ramsey Bay was then managed as a TURF whilst the remaining four grounds continued as  
 247        part of the RCA fishery. Point of Ayre (POA) was not included in this analysis due to lack of data.

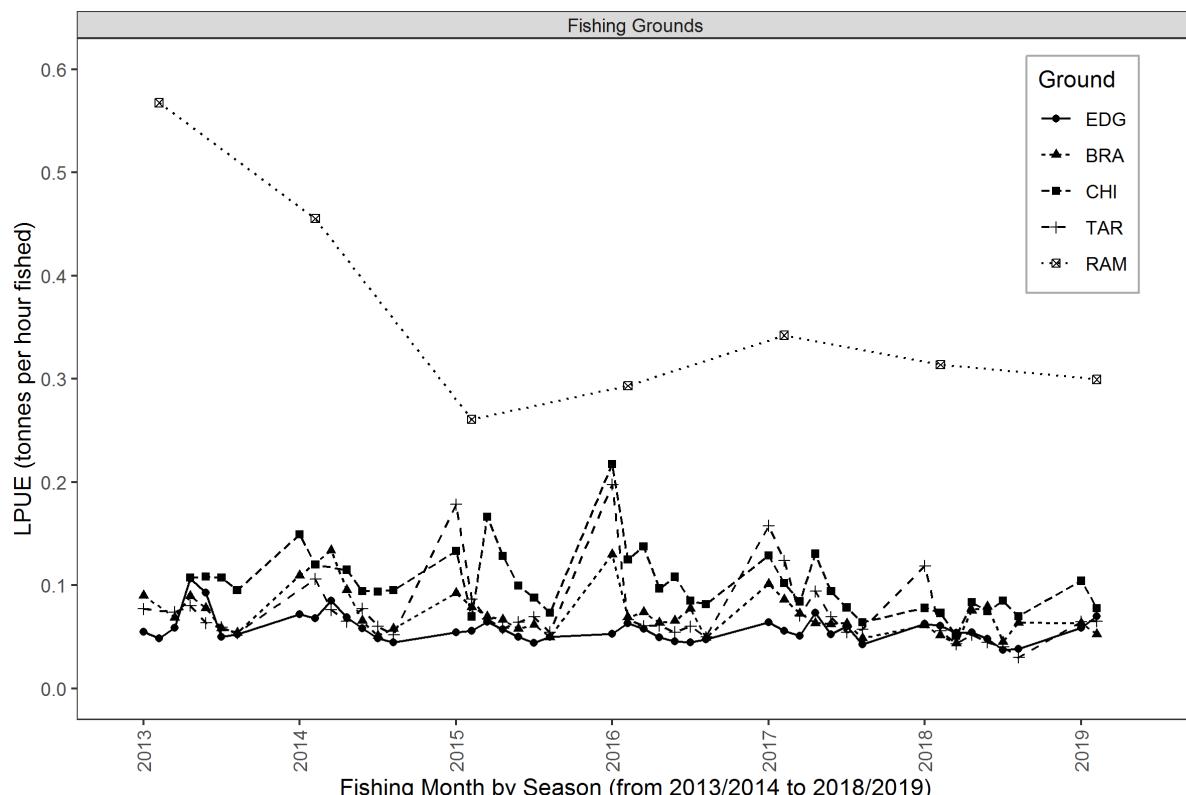
#### 248        3.2 Recent seasonal LPUE and population trends (2013 – 2019):

249        Figure 3 illustrates the typical intra-seasonal LPUE pattern (t HrF) within the four main RCA fishing  
 250        grounds with LPUE starting high at the beginning of the season (November/December) but declining  
 251        through the remaining months (January – May). The RAM TURF does not exhibit intra-seasonal  
 252        depletion of LPUE as it is open for less than one month each season (Figure 3). Inter-seasonal

253 variability in the starting LPUE at each ground is also illustrated in Figure 3 for the four main RCA fishing  
254 grounds. For the RAM TURF, although LPUE initially declined from the very high levels experienced  
255 following the three year closure, in contrast to the RCA grounds the starting LPUE has remained  
256 relatively high and stable since 2015 (Season 3) (Figure 3).

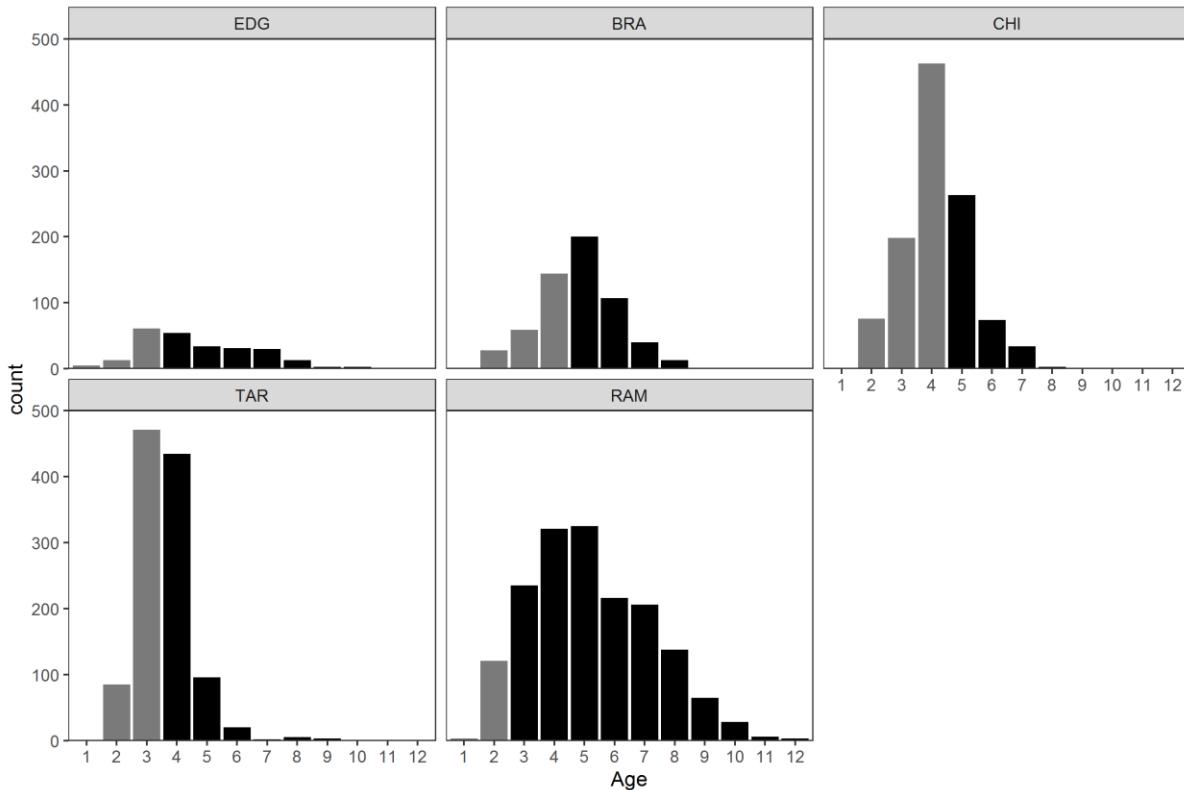
257  
258 The population structure for the five fishing grounds is displayed in Figure 4 with scallop survey sample  
259 data from 2013 – 2019, from the historic survey station for each ground (Figure 1), included. In the  
260 four main RCA fishing grounds the population structure typically skews towards younger age classes  
261 (i.e. scallops below or at the age at which they are considered large enough to recruit to the fishery)  
262 with an absence of significant numbers of scallops within the older age classes (Figure 4). The  
263 population structure at RAM prior to the closure was also skewed with 80% of scallops sampled in  
264 2008 within the year 2 or 3 age classes. However, following the three-year closure the population  
265 structure of sampled scallops in RAM TURF changed with a high proportion of sampled scallops above  
266 three years old (age of recruitment for RAM), and in recent years a distribution of individuals of up to  
267 12 years old (Figure 4). Recruitment of scallops is highly variable spatially and temporally and can be  
268 inferred from regular surveys of scallop densities at each main ground (Figure 5). High levels of  
269 recruitment are evidenced at some sites by peaks in scallop densities in certain years (i.e. CHI and TAR;  
270 Figure 5) whilst other sites have relatively stable levels of annual recruitment (i.e. BRA, EDG and POA;  
271 Figure 5). In the case of RAM, which prior to 2009 was part of the island-wide RCA fishery, the years  
272 when this site was surveyed indicated fairly low densities (~1 scallop per 100 m<sup>2</sup>) whilst post-closure  
273 densities have been maintained at around ~4-6 scallops per 100 m<sup>2</sup> (except for 2014 when the  
274 observed survey density was reduced; Figure 5).

275



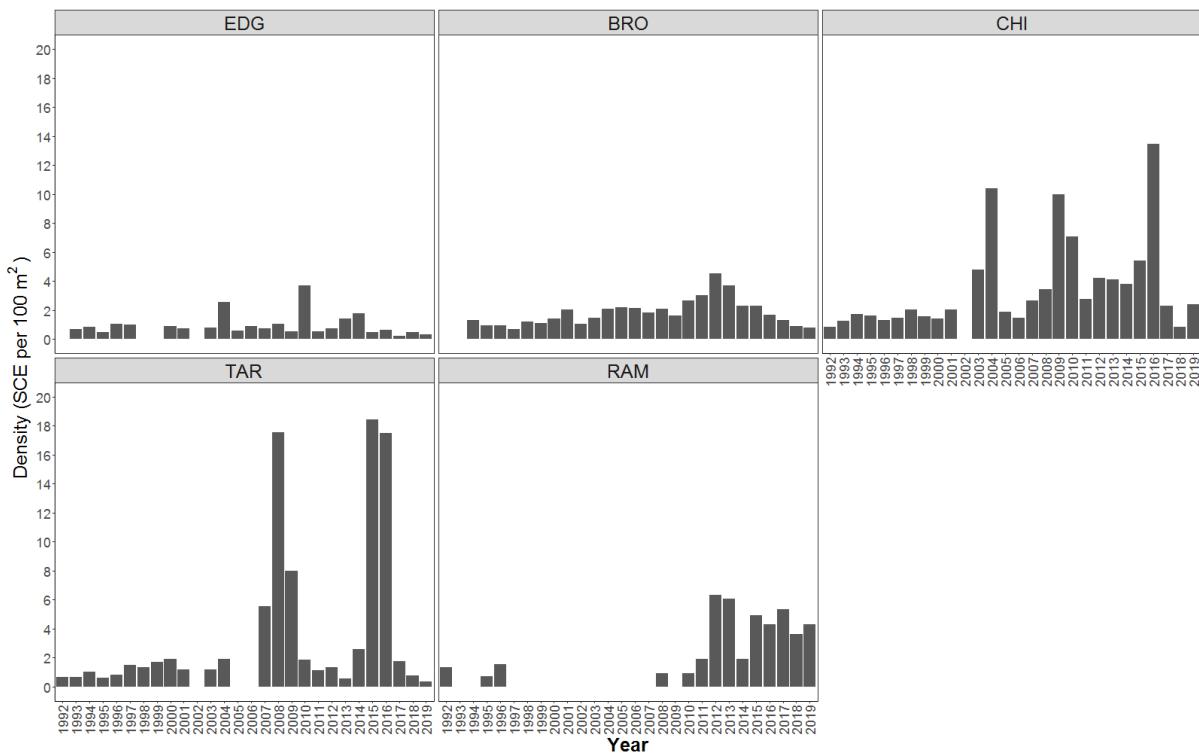
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277 Figure 3: Average monthly LPUE standardised to tonnes per hour fished for each of the five main fished grounds and displayed  
278 by month across six fishing seasons (2013/2014 to 2018/2019). The seasons are displayed along the x-axis with data points  
279 representing sequential months of the season (each season starts in November Year and finished in May Year<sup>1</sup>; RAM (Ramsey  
280 Bay) is only fished in one month (December) of each fishing season).



281

282 *Figure 4: Age frequency distribution for each of the five main fished grounds, using data from the historic survey station within*  
 283 *each ground, for the six fishing seasons (2013/2014 to 2018/2019) combined. The grey bars indicate the ages at which*  
 284 *scallops within that ground are typically under MLS and the black bars indicate the ages at which scallops within that ground*  
 285 *are typically over MLS.*



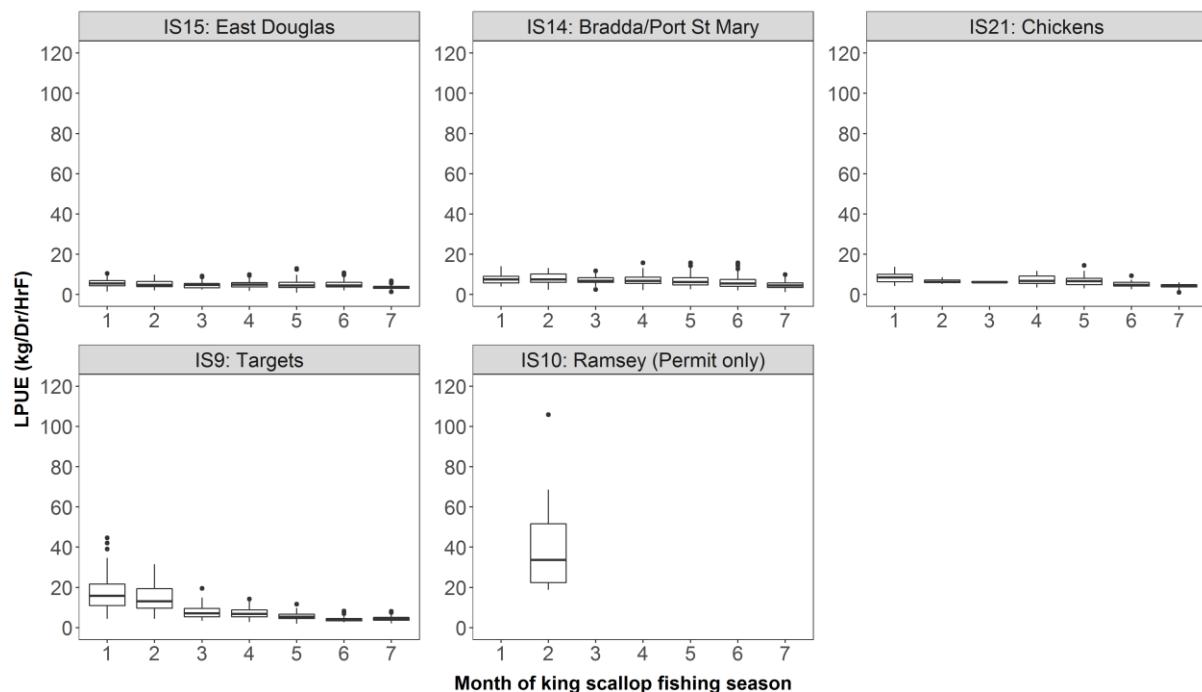
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287 *Figure 5: Scallop density per 100 m<sup>2</sup> from fixed historical stations sampled during the annual scallop survey in the Isle of Man*  
 288 *(EDG, BRO/BRA, CHI, TAR, and RAM). Survey data missing at some sites for some years.*

289

290 3.3: Commercial and environmental indicators (2017/2018 fishing season)

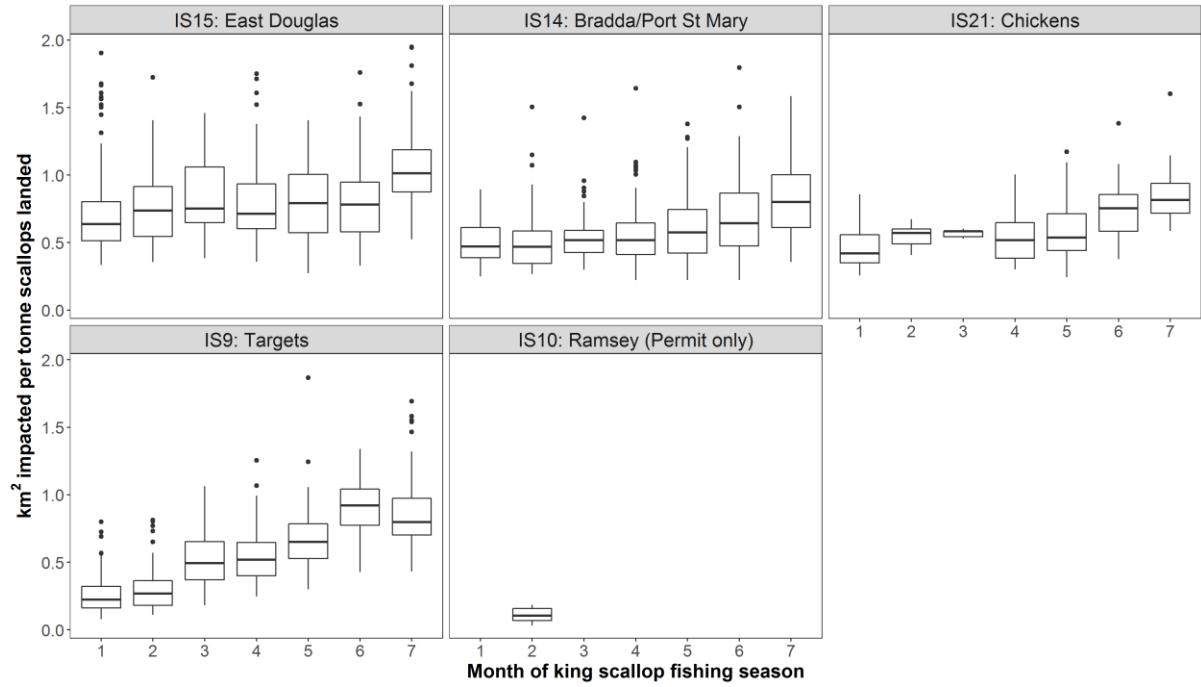
291 RAM TURF had a mean monthly LPUE of 40 kg/Dr/HrF for the 2017/2018 fishing season with total  
292 landings of around 52t. By comparison, three of the RCA fishery grounds had low mean monthly  
293 starting LPUE at under 10 kg/Dr/HrF (EDG, CHI, BRA), whilst TAR had the highest mean monthly  
294 starting LPUE for the RCA fishery at ~ 17 kg/Dr/HrF. Following total seasonal landings (i.e. all vessels)  
295 of 774t the mean monthly LPUE for TAR at the end of the season had dropped to ~ 4 kg/Dr/HrF and  
296 by the end of the fishing season all RCA grounds had monthly mean LPUE of less than 5 kg/Dr/HrF  
297 (Figure 6).



298

299 *Figure 6: Mean Landings per unit effort (LPUE) standardised to kg per dredge per hour fished (kg/Dr/HrF) displayed by fishing*  
300 *month for the 2017/2018 king scallop fishing season in the Isle of Man territorial sea. The fishing season begins in November*  
301 *each year. Total seasonal landings (i.e. all vessels) were TAR (774 t), CHI (665t), EDG (624t), BRA (561t) and RAM (52t).*

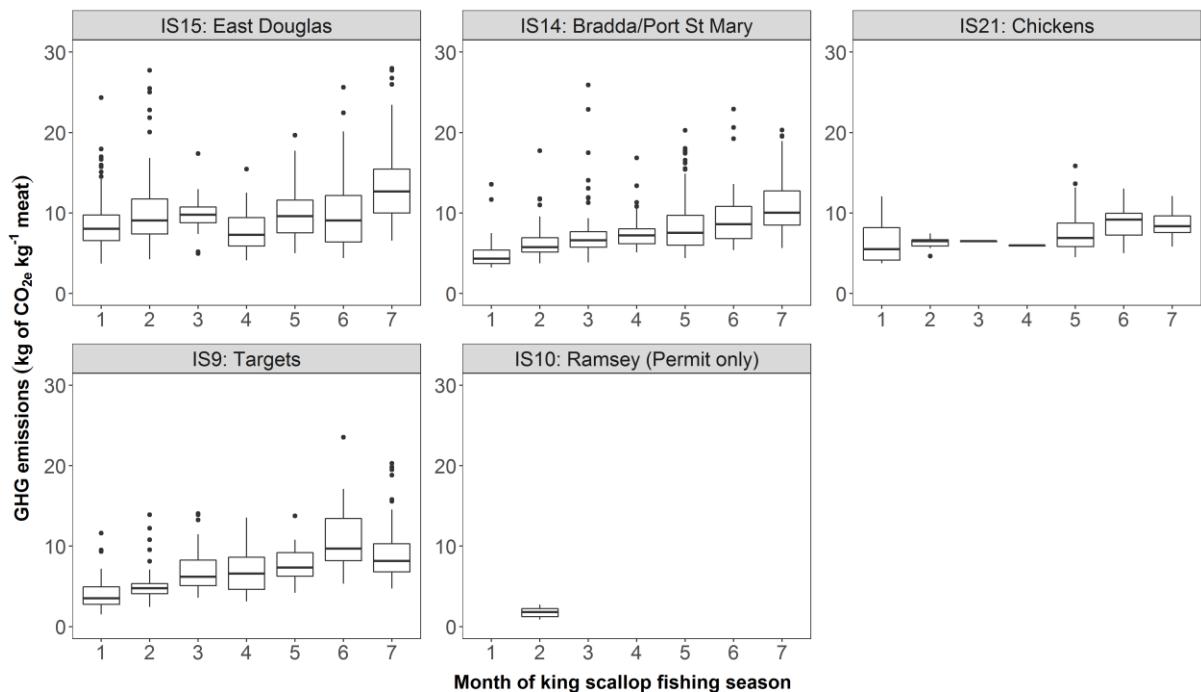
302 Scallop dredge gear impacted around 0.11 km<sup>2</sup> per t LSW landed in the RAM TURF. By comparison,  
303 three of the RCA fisheries had relatively high mean monthly starting area impacts of 0.47- 0.73 km<sup>2</sup>  
304 per t LSW landed (EDG, CHI, BRA). Whilst TAR had the lowest mean monthly starting area impacts for  
305 the RCA fishery at approximately 0.26 km<sup>2</sup> per t LSW landed. By the end of the fishing season all RCA  
306 grounds had increased the mean area impacted per tonne of LSW scallops landed to at least 0.86 km<sup>2</sup>  
307 per t LSW landed (Figure 7).



308

309 *Figure 7: The mean area impacted by scallop dredges per tonne of live shell weight scallop landed (km<sup>2</sup> impacted per t LSW  
310 landed) displayed by fishing month for the 2017/2018 king scallop fishing season in the Isle of Man territorial sea.*

311 Mean monthly greenhouse gas emissions within the RAM TURF were 1.73 kg of CO<sub>2e</sub> kg<sup>-1</sup> scallop meat.  
312 In comparison, three of the RCA fisheries had relatively high mean monthly starting emissions with  
313 5.5 to 8.6 kg of CO<sub>2e</sub> kg<sup>-1</sup> scallop meat (EDG, CHI, BRA). TAR had the lowest mean monthly starting  
314 emissions for the RCA fishery at approximately 4.07 kg of CO<sub>2e</sub> kg<sup>-1</sup> scallop meat. However, by the end  
315 of the fishing season all RCA grounds had increased GHG emissions to between 8.60 and 13.61 kg of  
316 CO<sub>2e</sub> kg<sup>-1</sup> scallop meat (Figure 8).



317

318 *Figure 8: Mean Greenhouse gas emissions (kg of CO<sub>2e</sub> kg<sup>-1</sup> scallop meat) displayed by fishing month for the 2017/2018 king  
319 scallop fishing season in the Isle of Man territorial sea.*

320

321 **4. Discussion**

322

323 **Boom not bust**

324 There is increasing concern from the seafood industry, scientists, NGOs and consumers about the  
325 environmental, ecological and economic sustainability of scallop dredge fisheries (Duncan et al. 2016).  
326 Globally, the use of conventional fisheries input controls, typically operating from centralised top-  
327 down governance, have had limited success in preventing issues such as overexploitation, habitat  
328 damage and bycatch (Grafton et al. 2006), as evidenced for many scallop fisheries. With some  
329 exceptions, the majority of European, towed-gear scallop fisheries have no quotas, daily catch limits  
330 or restrictions on overall vessel numbers targeting the fishery. In the absence of harvest controls,  
331 scallop densities are reduced quickly to relatively low levels, which introduces undesirable effects of  
332 economic inefficiencies and environmental impacts. As a result, many open-access scallop fisheries  
333 exhibit ‘boom and bust’ characteristics (Beukers-Stewart et al., 2003). Subsequent recovery of the  
334 ground and the stock can be slow, and takes many years (typically 3-4 years from experience on Manx  
335 grounds in 2009 and 2016), and in the interim, fishing is then focused on lower-density areas resulting  
336 in additional steaming time, fishing time, fuel use and seabed contact time for less reward.  
337

338 **Fuel use, costs and GHG Emissions**

339 Bottom trawling (including dredging) is energy-intensive (e.g. Schau et al., 2009). In this study fuel use  
340 coefficients for scallops dredging averaged 0.09 kg fuel/kg LSW scallop for the RAM TURF fishery  
341 during the 2017/2018 king scallop season. This was considerably lower than the values calculated for  
342 the RCA which ranged between 0.34 and 0.54 kg fuel/kg LSW scallop during the same period. The fuel  
343 use coefficient for the TURF is similar to values reported for less fuel-intensive metiers like purse  
344 seining fisheries (e.g. 0.02 -0.09 kg fuel/kg fish) (Schau et al., 2009) and substantially lower than values  
345 for more fuel-intensive metiers like international ground fish bottom trawl fisheries (0.28 – 1.50 kg  
346 fuel/kg fish; Schau et al. 2009) and shrimp trawl fisheries in Norway (up to 1.04 kg fuel/kg fish; Schau  
347 et al. 2009).

348 Fuel costs represent a significant portion of the associated costs in bottom trawl fishing. Increased  
349 fuel use therefore reduces profits. Mean fuel costs per tonne of LSW scallops (2017/2018) were at  
350 least 3 x higher for the RCA fishery compared to the TURF (range £182 to £290 for RCA and £47 for  
351 TURF; average fuel price was £0.45/litre; MFPO pers. Comm.). Fuel price is not a fixed variable and can  
352 fluctuate significantly from year to year with the cost differential having a greater impact on  
353 profitability when oil prices are high. For example, in 2005 (a high fuel price year) the fuel costs for  
354 shrimp trawling in Norway accounted for more than 30% of the catch value (Schau et al., 2009). By  
355 reducing fuel consumption fishers can improve their economic efficiency and reduce their  
356 environmental impacts. Energy performance should be considered a fundamental criteria in assessing  
357 the sustainability of towed-gear fisheries (Utne, 2008).

358 There is an increasing urgency for fisheries policy and management to better align with policies that  
359 address climate change in order to address consumer concerns regarding GHG emissions and the  
360 impact on fishers of increasing fuel prices (Driscoll & Tyedmers, 2010). For this reason carbon-  
361 efficiency metrics, which are already used in ecolabelling schemes like KRAV in Sweden, may be  
362 increasingly included as sustainability indicators for fisheries in the near future (e.g. Thrane et al. 2009;  
363 Madin & Macreadie, 2015). As the trend towards green consumerism increases, the fishing industry  
364 must adopt technologies and strategies that lower CO<sub>2</sub>e emissions in order to retain market access or

365 competitiveness. In order to quantify future improvements scallop fisheries should provide current  
366 benchmarks for this performance indicator. CO<sub>2</sub>e emissions for the RCA fishery (2017/2018) were at  
367 least 2-fold higher for the RCA fishery than that TURF (range 4.07 and 13.61 kg CO<sub>2</sub>e kg<sup>-1</sup> scallop meat  
368 for RCA and 1.73 kg CO<sub>2</sub>e kg<sup>-1</sup> scallop meat for TURF). Globally emissions intensity values for seafood  
369 have been estimated to range from 1 to 86 kg CO<sub>2</sub>e kg<sup>-1</sup> meat (Parker et al. 2018). The considerable  
370 differences in emissions among species and metiers were highlighted in a review by Nijdam et al.  
371 (2012) e.g. Spanish mussels ~ 1 kg CO<sub>2</sub>e kg<sup>-1</sup> meat (Iribarren et al. 2010), 86 kg CO<sub>2</sub>e kg<sup>-1</sup> meat for  
372 trawled Norway lobster (*Nephrops norvegicus*) (Ziegler & Valentinsson, 2008) and cod 1.7-4.4 kg CO<sub>2</sub>e  
373 kg<sup>-1</sup> fillet (Svanes et al. 2011). The TURF outperforms not only many wild-capture fishing industry  
374 systems in terms of GHG emissions, but also many land-based livestock systems (e.g. Poultry 2-6 kg  
375 CO<sub>2</sub>e kg<sup>-1</sup> meat, Pork ~ 4-11 kg CO<sub>2</sub>e kg<sup>-1</sup> meat and beef 9-129 kg CO<sub>2</sub>e kg<sup>-1</sup> meat; Nijdam et al. 2012).

376

### 377 **Commercial impacts, market performance and reliability**

378 Pre-fishery surveys enabled overall biomass estimates and fine-scale spatial density estimations across  
379 the TURF. The ground specific, biomass-linked TAC ensures biomass remains high and fishing ends  
380 before significant intra-seasonal reductions in LPUE. Fishing is also permitted only within the highest  
381 density areas, which promotes catch efficiency (i.e. high LPUE). Following a build-up of biomass during  
382 the three season closure, LPUE was very high in 2013 (season 1) at 0.57 t per hour fished. LPUE  
383 declined subsequently to 0.45 and 0.28 t per hour fished in Season 2 and 3 respectively, and has since  
384 remained stable at these relatively high levels of ~ 0.30 t per hour fished (Figure 3).

385 By contrast, the RCA fisheries typically target high-density patches at the start of the season  
386 (November/December) with monthly averages up to ~ 0.2 t per hour fished in November in good  
387 seasons (e.g. CHI and TAR season 4). However, the lack of biomass-linked, ground-specific TACs, means  
388 that these high-density beds are quickly depleted and vessels then sequentially target lower-density  
389 patches within the ground for the remainder of the fishing season (Figure 3). LPUE values at the end  
390 of the season are often significantly lower than the starting values (i.e. ~ 0.08 and 0.05 t per hour  
391 fished respectively at the end of season 4 in CHI and TAR respectively). High fishing mortality in the  
392 RCA on scallops over MLS skews the population towards smaller, younger scallops, leaving these  
393 grounds almost completely dependent on recruitment and growth of a single year class, during the  
394 closed season (i.e. June – October), to replenish the stock for the start of the next season (Figure 3).  
395 Thus the initial period of the fishing season can be associated with high LPUE in specific areas of the  
396 RCA when annual recruitment is high. Without sustainable limits on the TAC for each ground, or the  
397 presence of older age classes, rapid intra-seasonal declines in LPUE occurs (e.g. TAR and CHI; Figure  
398 5). This strategy reduces the average seasonal LPUE index closer to minimum economic viability. A  
399 period of recovery (seabed and stock) is then typically required before another recruitment peak can  
400 occur (i.e. “boom and bust” fishery).

401

402 Reliability of supply to the market is of vital importance for the fishing industry. The RCA grounds are  
403 predominantly dependent on the annual recruitment success of a single year class. The significant  
404 inter-annual variability in biomass and LPUE associated with recruit-driven scallop fisheries makes the  
405 sustainability of product for market supply difficult to guarantee. Conversely, in the TURF population  
406 the progressive increase in the presence of older age classes has effectively buffered against  
407 recruitment failure in any one year by increasing the variability in age-class components within the  
408 fishable stock (Figure 4). By harvesting the catch in December for the higher-value Christmas market  
409 fishers achieved a minimum £0.50 per kg more compared to the average price for the rest of the

410 season (a 22% increase in harvest value). In addition, the higher quality of the Ramsey Bay scallops  
411 compared to the rest of the RCA fishery (typically larger scallops with higher meat weight: e.g. 2019  
412 RAM was 7-9 scallops per lb; EDG was 13-14 scallops per lb and CHI was 14-15 scallops per lb; pers.  
413 comm. MFPO) has resulted in a premium price paid for the product. The TURF has thus enabled  
414 processors to develop a reputation for high quality, high-yielding scallops, particularly pre-Christmas,  
415 which has helped them retain market share, using the assured quality, larger size, and guaranteed  
416 availability from Ramsey Bay as a marketing tool for Isle of Man seafood products (pers. comm.  
417 MFPO).

418

#### 419 **Environmental benefits:**

420 The environmental impacts of food production have become an increasing concern for consumers and  
421 for the major retail chains in Europe it is perceived as a competitive advantage to promote the cause  
422 of the consumer (Schau et al., 2009). Consumer demand for dredged scallops may be threatened if  
423 the environmental impacts resulting from their production are considered outside acceptable  
424 consumer limits. Pre-fishery surveys in Ramsey Bay directed fishing to high-density areas (with areas  
425 that were of low-density, or that support vulnerable marine ecosystems voluntarily closed), thereby  
426 minimising the total footprint of the fishery and providing direct ecosystem benefits to surrounding  
427 areas. On average ≈ 95% of the TURF has remained unfished by mobile fishing gear each year. By  
428 focusing fishing activity on high-density areas, using data from pre-fishery surveys, and limiting the  
429 TAC in the TURF to approximately 15% of the estimated fishable biomass, the LPUE is maintained at  
430 relatively high levels and the area impacted is only 0.11 km<sup>2</sup> per t LSW landed, compared to between  
431 0.26 and 0.86 km<sup>2</sup> per t LSW landed for the RCA fishery. In the case of Ramsey Bay the security of  
432 restricted access tenure to the fishery, ensured by effective Government enforcement, created a  
433 context where fishers were able to consider marketing strategies which highlighted the reduced  
434 environmental impact of the fishery and which in turn helped secure its future market opportunities.

435

436 A limited fishing season (two to three weeks) within the TURF minimises scallop dredge disturbance  
437 during critical spawning, settlement and recruitment periods. By contrast the fishing grounds in the  
438 island's RCA fishery are fished by scallop dredges for up to 31 weeks each year (the fishery is closed  
439 annually from June to October). A shorter season allows greater recovery time for the seabed and  
440 associated communities impacted by dredges. It can also reduce the impacts on benthic structures  
441 upon which scallop spat settlement depends (e.g. hydroids, maerl etc.; Howarth et al. 2015; Oreska et  
442 al. 2017). The higher quality (size and yield) of Ramsey Bay scallops, and resulting premium price,  
443 compared to the rest of the RCA territorial sea, may simply be linked to better local physical and  
444 biological conditions (i.e. water current, food availability, temperature etc.), which are known to  
445 impact growth and gamete production (e.g. Harris & Stokesbury 2006, Shephard et al. 2010).  
446 However, the reduction in frequency of physical interactions between scallop gear and scallops in  
447 Ramsey Bay, as a result of the limited fishing season and TAC, may also be linked to the enhanced  
448 quantity and yield of scallops in the TURF compared to the RCA, as reported by Kaiser et al. (2007)  
449 where the gonads of scallops in a closed area were on average 25% larger compared to gonads from  
450 commercially fished grounds.

451

#### 452 **Success and challenges for sustainable scallop fishery management**

453 Changes in management of most European scallop fisheries are required if stock biomass, commercial  
454 profitability, environmental efficiency and consumer demand are to be maintained. It is acknowledged

455 that a suite of management options exist ranging from open-access to full rights-based cooperative  
456 management with a number of intermediate management options in between. Where the legislative  
457 context restricts rights-based management, traditional management methods such as limited entry,  
458 restrictions on effort and limits on total catch through government licencing can still provide  
459 successful improvements to scallop management, as long as fishing capacity is well matched to scallop  
460 resource productivity (Orensanz et al., 2016). A successful approach based on traditional management  
461 systems is demonstrated in the Saint Brieuc fishery in France where intensive management is framed  
462 through government legislation. A restricted licence system was introduced in 1963 to avoid  
463 overfishing and effort was then further restricted through limits on time at sea per day and a days-at-  
464 sea scheme which resulted in dramatic increases in scallop catch rates (Beukers-Stewart & Beukers-  
465 Stewart 2009). The majority of the US sea scallop fishery has also successfully implemented a range  
466 of traditional management measures after it was officially declared overfished in 1997 (Beukers-  
467 Stewart & Beukers-Stewart 2009). Measures included limited access permits, caps on days-at-sea,  
468 rotational closures, individual trip catch limits and fleet-wide annual catch limits (Orensanz et al.,  
469 2016). These measures also proved successful in improving biomass and size class structure of the  
470 scallop stock (Beukers-Stewart & Beukers-Stewart 2009). The marked change in management of the  
471 US sea scallop fishery was triggered by a crisis that arose from over-fishing and has similarities to the  
472 Ramsey Bay fishery that was closed due to its overfished status, providing the necessary ‘pause’ in  
473 fishing to permit stock recovery and the introduction of a novel approach to management.

474

475 Where the legislative context does permit, the additional environmental and ecosystem based  
476 management incentives provided by rights-based management schemes may be significant for  
477 fisheries like scallops. Rights-based management can provide a means to improve not only the  
478 commercial efficiency of scallop fisheries but also their environmental status and consumer image, as  
479 demonstrated in Ramsey Bay. A range of rights-based management systems have been successfully  
480 adopted by scallop fisheries. For example, Enterprise Allocations (EAs) were introduced in the  
481 Canadian sea scallop fishery at Georges Bank in 1986 and changed the behaviour of the fleet, with  
482 voluntary closures of juvenile areas and fleet modernization and rationalisation, compared to  
483 management using traditional input controls (Stevens et al., 2008). Since the implementation of EAs  
484 in 1986 fishing effort has reduced and catch rates have tripled (Beukers-Stewart & Beukers-Stewart  
485 2009). The territorial user-rights management approach used in Ramsey Bay conferred a level of  
486 ownership for the resource on the fishers, within a defined fishing area. At the start of the Ramsey  
487 Bay TURF, there were individual differences in fisher’s attitudes to this resource management  
488 approach, with some fishers perceiving that the tighter controls imposed denied them the freedom to  
489 fish in a manner that suited them. A two-way exchange of information between scientists and the  
490 fishers, which included an annual discussion regarding survey results and harvesting options,  
491 underpinned the annual decision making process on how, when, and how much to fish. This  
492 cooperative and participatory approach, whereby the fishers ultimately became responsible for  
493 undertaking the surveys, and subsequent harvesting of the resource, increased fisher confidence and  
494 acceptance of the management strategy and supporting data. Allowing fishers the opportunity to see  
495 for themselves the potential of the fishery to achieve a sustained and improved status has reassured  
496 those that might have doubted the veracity of the approach. Importantly, the security of tenure has  
497 enabled the fishers to move away from a ‘race to fish’ management style and instead incentivised the  
498 implementation of management measures to reduce fishing pressure, implement conservation  
499 measures, enhance stocks and the habitat on which the target species depend; and to consider the  
500 long-term wellbeing of industry members. These management measures have not only proved  
501 successful in improving the biomass and size class structure of the scallop stock and the efficiency of

502 commercial harvesting within the fishing area but, just as importantly, they have also provided  
503 benefits for the wider ecosystem and for the market potential of the product.

504

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