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The camera drop frame prior to its deployment from the aft deck of FRV *Alba na Mara*.

Scallop Abundance in the Lamlash Bay No Take Zone: A Baseline Study

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Abstract

In response to concern over the damaging effects of scallop dredging, there is a readiness among marine planners and conservation organisations to utilise spatial closures as a tool in the management of the fishery. Although primarily used to protect key habitats and species and enhance biodiversity, it is thought that marine protected areas may also help re-establish or enhance stocks. Lamlash Bay, in the Firth of Clyde, was declared Scotland's first No Take Zone (NTZ) in 2008. The cessation of bottom trawl and dredge fishing in the NTZ provides an excellent opportunity to investigate the re-colonisation of newly protected areas by scallops. This report presents the results of photographic surveys undertaken by Marine Scotland Science in July 2009 and November 2010 during the first phase of a study of the NTZ's effects. It includes baseline abundance data for the great scallop, *Pecten maximus*, and the queen scallop, *Aequipecten opercularis* and a preliminary analysis of densities inside and outside the NTZ. There was insufficient evidence that the NTZ contains higher densities of adult *P. maximus* or *A. opercularis* than reference areas sited in adjacent waters, or that abundances within the NTZ increased more rapidly than elsewhere. Given the short time scales involved in this the initial phase of the study, this result is not entirely unexpected as the NTZ is unlikely to have had sufficient time to affect abundance levels. The analyses does suggest, however, that the reference areas chosen to test the performance of the NTZ over time are comparable with the NTZ and that the data collected provide a suitable baseline for a longer term study of changes in scallop abundance within Lamlash Bay.

Introduction

Of current fishing practice, meta-analyses studying a wide range of towed bottom-fishing gears suggest that scallop dredging is responsible for some of the most damaging effects to the benthic habitat (Collie *et al.*, 2000; Kaiser *et al.*, 2006). Small-scale studies provide empirical evidence that scallop dredging results in the destruction and removal of many non-target, infaunal and epifaunal species as well as the physical disturbance of the sediment (Eleftheriou and Robertson, 1992; Thrush *et al.*, 1995; Kaiser *et al.*, 1996; Currie and Parry, 1996; Hall-Spencer and Moore, 2000; Hinz *et al.*, 2011). Set alongside this pattern of disturbance, scallop stocks in some of the main fishing areas in Scottish waters have declined over the last decade (Howell *et al.*, 2006; Keltz and Bailey, 2010). As a result, fishery managers, marine planners and conservation organisations are giving greater consideration to spatial closures in the management of the scallop fishery.

Scallop Stocks

The great scallop, *Pecten maximus*, and to a much lesser extent the smaller queen scallop, *Aequipecten opercularis*, are of economic importance to the UK fishing industry (Beukers-Stewart and Beukers-Stewart, 2009). The fishery for *P. maximus* in Scotland accounts for approximately half of the UK scallop fishery and is Scotland's second most valuable shellfish resource after *Nephrops norvegicus.* In 2010, Scottish vessels landed 18,762 tonnes of *P. maximus* and 8,373 tonnes of *A. opercularis,* with a first sale value of £31.9 m and £3.2 m respectively (Scottish Sea Fisheries Statistics 2010).

Marine Scotland Science (MSS) evaluates stocks of *P. maximus* around Scotland based on commercial catch-at-age and survey data. Full stock assessments are carried out for West of Kintyre, North West, North East and Shetland scallop stocks, and catch data are presented for areas where there are insufficient data to perform analytical assessments e.g. Clyde, Irish Sea, Orkney and East coast. There are no agreed biomass or reference points for scallops stocks and advice is based on the estimates of recent fishing mortality, recruitment and biomass in relation to historical values. Assessments of stocks to the west of Scotland (West of Kintyre and North West Management areas), reveal fluctuations in catch and recruitment and long term decline in spawning stock biomass. Advice recommends a reduction in fishing effort and new measures to increase spawning stock biomass, for example an increase in minimum landing size (Dobby *et al.*, in press). Stocks of *A. opercularis* are not assessed by MSS.

The Firth of Clyde

The dredge fishery for *P. maximus* in Scotland began in the early 1930s as a seasonal fishery prosecuted by small inshore vessels in the Clyde. The fishery developed rapidly during the late 1960s and early 1970s, expanding through the rest of Scotland and is now a year round activity. The commercial fishery for *P. maximus* in the Clyde began in the 1960s and landings have fluctuated since then, declining to under 20 tonnes in 1990 and increasing to over 500 tonnes in 2010 (Dobby *et al*., in press). *P. maximus* stocks in the Clyde are not assessed by MSS due to insufficient age composition data and no survey data available for this area.

The commercial fishery for *A. opercularis* is primarily based in the Irish Sea. In 2010, UK vessels landed 6635 tonnes of *A. opercularis* into Scotland from the Irish Sea and only 46 tonnes from the Clyde (MSS data, 2011).

Methods of capture

The most prevalent method of catching *P. maximus* in Scotland is by dredge. The dredges used are normally of the 'Newhaven' type and are fitted with a spring-loaded tooth bar that allows the dredge to pass over hard ground (Figure 2). The spring loaded action of the toothed bar allows the teeth to flex backwards, preventing the dredge from snagging on harder ground, and also improves the catch efficiency of the dredge (Kaiser *et al.*, 1996). The size of the teeth, their spacing, and the diameter of the mesh rings used to make up the collecting bag all combine to affect the size of animals caught up in the dredge (Eleftheriou and Robertson, 1992). Although accounting for only 5% of landings (Keltz and Bailey, 2010), *P. maximus* is also fished by commercial-divers working from small vessels in areas of shallow water (typically under 40 m). This fishery tends to take place in rockier areas away from the dredge fishery and generally targets only larger individuals. Caught using towed fishing gear, *A. opercularis* are taken using either skid dredges (a modified Newhaven dredge) or modified otter trawls (Mason, 1983).

Conserving Stocks

Declining stocks of *P. maximus* in Scottish waters during the latter part of the 1990s prompted the introduction of measures to limit fishing effort and mortality, including a scallop fishing vessel licensing scheme and a minimum landing size of 100 mm (Bailey *et al*., 1998; Howell *et al.*, 2006). In 2003, gear restrictions outlined in The Prohibition of Fishing for Scallops (Scotland) Order 2003 (SSI 2003/371), made under sections 5 and 15(3) of the Sea Fish (Conservation) Act 1967(1), limit the number of dredges a vessel can tow to a maximum of 8-per-side in Scottish inshore waters (< 6 Nm), 10-per-side in any other part of the territorial sea of the UK adjacent to Scotland and up to 14-per-side in any other area of the Scottish zone. Additional measures for the management of the fishery are currently being considered by Scottish Government in conjunction with stakeholder groups.

Spatial Management Measures

In response to concerns about the damaging effects of scallop dredging there has been a drive to control the activity of the fishery within a broader framework, such as an Ecosystem Approach to Fisheries Management (EAFM). This is manifest among marine planners and conservation organisations in the greater consideration of spatial closures and Marine Protected Areas (MPAs) in the management of the scallop fishery (Hinz *et al.*, 2011). Although primarily used to protect key conservation species and enhance benthic biodiversity, it is thought that MPAs may also help re-establish or enhance fish and shellfish stocks (Roberts *et al.*, 2001; Gell and Roberts 2003), and, consequently, their use as a fisheries management tool has been advocated (Field *et al.*, 2006). The assent of the Marine (Scotland) Act 2010 allows for the designation and management of Nature Conservation MPAs for the protection and enhancement of marine biodiversity in Scottish waters and for the designation of MPAs for demonstration and research purposes. The Act also includes provision for considering community proposals for Nature Conservation and Demonstration/Research MPAs.

The reasons for establishing MPAs, the specified objectives, and the limits imposed on activities within an MPA can vary considerably. In some cases MPAs may impose limits on certain activities at certain times whereas in others there may be a complete ban on a wide range of activities. No Take Zones (NTZs) represent a more stringent form of protection where all forms of exploitation are prohibited. However, the question as to whether MPAs are an effective fisheries management tool in the conservation of fish and shellfish stocks is, as yet, unanswered (Kaiser *et al.*, 2005). There is conflicting evidence relating to the efficacy of MPAs, which relates in part to the desire for newly established MPAs to achieve multiple, and often contradictory, objectives (Roberts *et al.*, 2003). For example, MPAs set up to preserve the habitat and biodiversity within a particular area may not, in some instances, maximise stock yields (Hasting and Botsford, 2003), although it is likely to be the case that a partial enhancement of stocks does occur. In terms of single species management, MPAs are expected to control fishing mortality, and by doing so increase abundance and restore age-structure to that more typical of an unexploited population. With this comes the potential for net export, both in terms of adults and larvae from the MPA, and the possibility that stocks in neighbouring areas may also be enhanced (Russ *et al.*, 2004; Halpern *et al.*, 2009; Stobart *et al.*, 2009). The effectiveness of MPAs in enhancing stocks is thought to depend on several factors, such as the life-history characteristics of protected species; the size of the MPA in relation to the stock or population; density dependent effects within the stock; the effect of re-distributing fishing effort to other waters, and the level to which prohibition orders are enforced (Halpern, 2003). Hence, although the establishment an MPA is unlikely to worsen the position of a vulnerable species within a defined area, its potential to restore particular stocks in a targeted or predictable manner can be overstated.

MPAs and their use for mitigating the effects of scallop fishing

Scallop fishing removes individuals from the stock and causes physical damage, at times fatal, to scallops lying in the path of the dredges (Beukers-Stewart *et al.*, 2001; Stokesbury *et al.*, 2011). Furthermore, the action of the passing dredge tends to remove larger individuals from the seabed and, since larger individuals in a given stock tend to be older (Chapman *et al.*, 1977), dredging also serves to truncate the age structures of local populations in areas which are fished (Beukers-Stewart *et al.*, 2005). This can have implications for reproductive output as smaller, younger individuals produce fewer larvae (Mason, 1983). Since scallop dredging has a homogenising effect on the seabed (Jenkins *et al.*, 2001), it may also affect recruitment indirectly through the removal of suitable structures necessary for the attachment of scallop spat (Mason, 1983; Kamenos *et al.*, 2004). Such effects should however be considered in the context of wider environmental influences on recruitment and the marked year on year variations in recruitment that are typically observed for scallops stocks (Beukers-Stewart *et al.*, 2005).

In the face of declining stocks and poor recruitment, it has been argued that scallops stocks within Scottish waters would benefit from the protection afforded to them by spatial management measures, particularly MPAs. Potential benefits are several-fold, with the imposition of a MPA serving to simplify and strengthen fisheries management measures (Murawski *et al.*, 2000; Pauly, 2009), increase population abundance (e.g. Roberts 1995), restore age structures to pre-fished levels (e.g. Holland and Brazee, 1996), and increase biodiversity (e.g. Argady, 1994). In the context of scallop fishery management MPAs may be particularly beneficial because adult scallops are relatively immobile and specific to particular habitats (Mason, 1983; Kaiser, 2005). Moreover, given the highly variable levels of recruitment, and the lack of clear stock recruitment relationship for scallop stocks, there is little basis for traditional management techniques based on predictive dynamic models and Total Allowable Catches (Beukers-Stewart *et al.*, 2005). However, it should be noted that, even if increases in abundance are realised following the establishment of an MPA, density-dependent effects and adult mortality may serve to limit the total stock biomass an area can support (McGilliard and Hilborn, 2008).

There is however evidence that scallop stocks benefit from spatial management, at least within the boundaries of the protected areas. Enhanced stock numbers of *P. maximus* have been recorded in the Isle of Man in a 2 km^2 area that has been closed to scallop dredging since 1989 (Beukers-Stewart *et al.*, 2005). Four years after the closure of the Georges Bank on the eastern seaboard of Canada to towed gears in 1994, surveys reported the highest densities and largest individuals of the sea scallop, *Placopecten magellanicus*, ever recorded in the area (Murawski *et al.*, 2000; Stokesbury, 2002). On the other hand, even in the absence of fishing, mass mortality events have been documented within MPA boundaries. Stokesbury *et al.* (2007) found that larger, and possibly older, *P. magellanicus* experienced high rates of mortality (35%) between 2004 and 2005 in a closed area in the Great South Channel, USA.

The NTZ within Lamlash Bay

Lamlash Bay in the Firth of Clyde was declared Scotland's first No Take Zone (NTZ) on 20 September 2008. All fishing for sea fish, including scallops, is prohibited within the confines of the 2.65 km^2 NTZ under by means of an Order, The Inshore Fishing (Prohibition on Fishing) (Lamlash Bay) (Scotland) Order 2008 made under section 1(1) of the Inshore Fishing (Scotland) Act 1984. Lamlash Bay is located on the south eastern shore of the island of Arran and is sheltered, with the exception of entrances to the south and north-east, by the Holy Island to the east (Figure 3). The NTZ was established in response to concerns relating to the effects of fishing on local fish and shellfish populations in general, and *P. maximus* in particular, and to the damage to both seabed and epifauna resulting from the prosecution of the scallop fishery (COAST, 2005).

The cessation of fishing activity in Lamlash Bay provides an excellent opportunity to investigate the recovery of scallop stocks within a recently established marine protected area. It also provides a unique opportunity to examine the ecological consequences of using spatial closures as a fishery management tool.

Aims of the Study

The aims of this study were to: i) develop photographic survey techniques for scallops appropriate for Scottish inshore waters, ii) identify reference areas suitable for the future evaluation of the NTZ, iii) obtain baseline abundance data for *P. maximus* and *A. opercularis* in Lamlash Bay and in the immediate vicinity. In this the initial phase of the study, abundance data were collected in both 2009 and 2010. Thus it was also possible to examine whether the NTZ had had an early effect on scallop abundance.

Methods

Given that the removal of scallops is prohibited within the NTZ it was not possible to assess scallop stocks on the basis of experimental fishing or fishery data. As an alternative, two, non-destructive photographic surveys of the seabed within and around Lamlash Bay were carried out by MSS in July 2009 and November 2010. Surveys were conducted in three areas: the NTZ and two reference areas that acted as controls.

The Drop Frame Camera System

The camera system used in this study was developed by MSS and was designed to capture images of a known area of seabed. The use of a photographic survey technique has been successfully used to assess abundance in sea scallops, *P. magellanicus*, (see Stokesbury and Harris, 2006) although it should be noted that this species of scallop does not recess into the substrate to the same extent as *P. maximus.* The system used in the present study (Figure 4) comprised a pyramidal frame fitted with a Kongsberg OE14-208 digital still camera (Kongsberg Gruppen ASA, Norway). Side elevated video images were recorded onto a hard disk recorder using a Micro-SeaCam 2000 video camera (Deepsea Power and Light, California). This assisted in the identification of recessed *P. maximus* post-survey where there was uncertainty. Illumination for both cameras was provided by eight SeaLED, MK3 LED lamps (Seatronics Ltd., Aberdeen) arranged in a ring around the field of view. A critical feature of the drop frame is that it rests on the seabed while digital still images are taken. This produced a fixed, focal length of 1.8 m. The camera was set at aperture of *f*/5 with shutter speed selected automatically. Images were post-processed using Photoshop CS3 (Adobe Systems, California). This proved to increase image contrast and assist species identification.

Photographic Surveys

Surveys were carried out on board “RV *Aora*” in 2009 and on “FRV *Alba na Mara*” in 2010. The survey examined 100 stations in each of the three study areas, except in the NTZ in 2009 when 110 stations were visited. Station positions were, in the first instance, determined using a random spatial pattern generated within the ArcGIS (geographic information system) environment using Hawth's Analysis Tools (Beyer, 2004). The positions of some stations were adjusted during the survey if the original station position proved unnavigable. To maintain consistency, especially in case of the NTZ, the placement of stations was adhered to as far as was practically possible across years. A necessary exception to this occurred during the survey of the two reference areas in 2010 as the boundaries of these were re-drawn prior to the survey. The planned, re-drawing exercise was done after the first survey to ensure that all stations were sited on substrates known to be suitable habitats for scallops. The re-drawing exercise also aimed to produce a long-term, fully-controlled before and after survey design using reference areas that are comparable in terms of depth, substrate type and component biotope to those of the NTZ.

Four 1.85 m^2 quadrat images of the seabed were obtained at each station. Time, depth, latitude and longitude were also recorded. A shipboard video monitoring system ensured that the camera operator avoided taking images from overlapping quadrats. By accounting for edge effects (see Krebs, 1989; Stokesbury, 2002), the sampled area within each quadrat could be increased. In the case of *P. maximus*, the sampled area was 2 m^2. This was calculated by adding 56.5 mm - the average half, shell height of *P. maximus* taken from market sampling data (Marine Scotland Science data, 2011) - to each edge of the quadrat. Using four such quadrats yielded a surveyed area of 8 m^2 at each station. The effective area sampled for the smaller *A. opercularis* was 1.94 m^2, based on an average half shell height of 34.3 mm (Marine Scotland Science data, 2011).

Data

All images were analysed post-survey. The number of scallops of each species (*P. maximus and A. opercularis*) present in each quadrat and the substrate type were recorded. Since the photographic technique used made it difficult to identify very small individuals to species, only ‘adults’ were counted. *Pecten maximus and A. opercularis* individuals with estimated shell heights of > 80 mm and >40 mm, respectively, were classified as adults. Although drop camera frames have been used to estimate scallop shell heights previously (e.g. Stokesbury *et al.* 2004), errors in size data collected from visual survey methods increase the frequency and size of the largest and smallest individuals, potentially biasing growth, mortality, and biomass estimates (Jacobson *et al.*, 2010). Due to the relatively small numbers of scallops encountered during the survey, and the fact that a high degree of precision is likely to be required to discern between years, no estimates of size were used in this study.

Sediments were classified on the basis of observation as: (1) mud or mud/sand, (2) sand, (3) sand/gravel (4) gravel (5) gravel/boulders. To simplify classification, shell debris were classed as gravel when amongst gravel beds.

Statistical Analyses

Although the present study was designed to develop survey protocols and gather baseline abundance data, it was also possible to investigate the change in scallop density in the NTZ between 2009 and 2010, and to compare these changes to those in the two reference areas over the same time period. Since boundaries for the reference areas were redrawn in 2010, only data from those stations which lay within the 2010 boundaries were compared. The redrawing process meant that 38 stations of a possible 100 were analysed statistically in each of the 2009 reference areas.

Differences in the densities of *P. maximus* and *A. opercularis* were initially tested using a generalized, mixed model that included protection status (two levels: NTZ or reference area) and year (two levels: 2009 and 2010) as explanatory variables, with station included as an additional random effect (McCulloch *et al*., 2008). Counts were modelled using a Poisson probability distribution and an Akaike information criterion (AIC) was used to select between models (Akaike, 1974). The random station effect within the final model was tested by comparison to a more parsimonious model that excluded station and was modelled within a generalized linear model framework (McCullagh and Nelder, 1989). All modelling was carried out within R and packages associated with generalized mixed models and generalized linear models (R core development team, 2011).

Results

1. Camera Survey Technique

In total, 2,440 quadrat images of the seabed in and around Lamlash Bay were obtained during the two surveys, and of these 1,944 quadrats were used in subsequent statistical analyses. Poor water clarity caused by a seasonal bloom of plankton was apparent in images collected from the summer survey of 2009. This problem was mitigated by the use of image-processing techniques. An example of the quadrat images collected during these surveys is given in Figure 5.

2. Identification of Survey Areas

Two reference areas were identified during the preliminary survey in 2009. These were adjacent to the NTZ, one within the bay and one outside, lay to the west and east of its boundaries, and were in waters of a similar depth (15-35 m). A map of substrate type derived from 2009 survey data and the area boundaries are shown in Figure 6. Following a post-survey analysis of the 2009 image data, prior to the 2010 survey, the boundaries of both reference areas were redrawn to encompass only those areas providing suitable habitat for scallops. Substrate types observed in the survey quadrats in the both 2009 and 2010 surveys are shown in (Figure 7).

3. Baseline estimates of Mean Density

P. maximus

The mean densities (quoted to two significant figures) of *P. maximus* within the NTZ were 0.040 m^2 (±S.E. = 0.007, *N* = 35) and 0.051 m^2 (±S.E. = 0.007, *N* = 41) in 2009 and 2010, respectively. These compared with mean densities of 0.043 m^2 (±S.E. = 0.013, *N* = 13) and 0.040 m^2 (±S.E. = 0.008, *N* = 32) in 2009 and 2010 in the east reference area, and 0.033 m^2 (±S.E. = 0.012, *N* = 10) and 0.045 m^2 (±S.E. = 0.007, *N* = 36) in 2009 and 2010 in the west reference area (Figure 8).

A. opercularis

The mean densities (quoted to two significant figures) of *A. opercularis* within the NTZ were 0.032 m^2 (±S.E. = 0.006, *N* = 27) and 0.019 m^2 (±S.E. = 0.006, *N* = 15) in 2009 and 2010, respectively. These compared with mean densities of 0.024 m^2 (±S.E. = 0.009, *N* = 7) and 0.024 m^2 (±S.E. = 0.05, *N* = 19) in 2009 and 2010 in the east reference area, and 0.061 m^2 (±S.E. = 0. 0.01, *N* = 18) and 0.017m^2 (±S.E. = 0.006, *N* = 13) in 2009 and 2010 in the west reference area (Figure 9).

4. Assessing changes in Stock Abundance from 2009 to 2010

P. maximus

Densities of *P. maximus* within the NTZ and the two reference areas, when modelling data from both 2009 and 2010, were not found to be significantly different: the addition of protection status to the intercept model was non-significant (Chisq = 0.20, d.f. = 1, P = 0.65). Densities were also not found to differ statistically between 2009 and 2010: the addition of year to the intercept model was non-significant (Chisq = 1.03, d.f. = 1, P = 0.31).

A. opercularis

In contrast to *P. maximus*, densities of *A. opercularis* were found to differ statistically between 2009 and 2010 (z = 2.64, d.f. =1, P = 0.008). However, densities of *A. opercularis* within the NTZ and reference areas were not found to be statistically different: here, the addition of protection status to a statistical model including the effect of year was non-significant (Chisq = 0.45, d.f. = 1, P = 0.50).

2010 Data

Reference areas in the 2009 survey yielded low abundance counts; for example, a total of 10 *P. maximus* were counted in quadrats in the eastern reference area. This low number was the result of the redrawing process that included only 38 stations in each of the 2009 reference areas. Analysis of the 2010 data alone, where 100 stations were surveyed in all three areas, did not reveal any differences in abundance between the NTZ and reference areas for either species (*P. maximus*, Chisq = 0.41, d.f.=1, P = 0.52: *A. opercularis*, Chisq = 0.01, d.f.=1, P = 0.90).

Discussion

The methods developed during the study allow for the collection of suitable baseline data for a long-term study of scallop abundance within Lamlash Bay. Although, at this stage in the study, the sampling protocol was not intended to be implemented as a fully balanced statistical design with adequate controls, a comparison of stock abundance between the NTZ and two reference areas, and across the two sampled years, was possible. The three areas surveyed in 2010 circumscribed substrates upon which scallops are typically found and were in waters of a suitable depth. The redrawing of the two reference areas in 2010 was performed to exclude large areas of unsuitable habitat. Scallop grounds are highly defined in terms of substrate, with individuals colonising substrata dominated by clean firm sand, fine gravel or sandy gravel (Mason, 1983). It is envisaged that any future surveys will follow the 2010 survey design.

On the basis of the analysis of data collected in 2009 and 2010 we were unable to find evidence that the Lamlash Bay NTZ held higher densities of adult *P. maximus* or *A. opercularis* than areas in adjacent waters in either year, or that abundances within the NTZ increased more rapidly during the one year monitoring period than elsewhere. The analysis, combined with a visual inspection of substrate, does suggest, however, that the reference areas chosen to test the performance of the NTZ do present useful comparisons. A significant effect of time was found for *A. opercularis* but this was driven by elevated abundance levels in the reference area to the west of the NTZ. This area is situated within Lamlash Bay, and it is possible that it benefits partially from the protected status of the NTZ due to a reduction in fishing activity caused by the truncation of historical trawl paths.

Although the analysis does not support the hypothesis that the NTZ within Lamlash Bay has enhanced scallop numbers, it should be stressed that the data collected were intended to perform as baseline data. Indeed, the population abundance of adult *P. maximus or A. opercularis* is unlikely to have changed appreciably in the year between the two surveys. Short term benefits of the NTZ during the short survey period in this study would most likely be manifest as an increase in the number of scallop spat. However, the use of the drop frame photographic technique is unlikely to detect such a change reliably due to the small size of spat. Other preliminary data that suggest the NTZ within Lamlash is having such an effect do exist. A 2010 dive survey conducted within Lamlash found the numbers of juvenile scallop spat (both *P. maximus* and *A. opercularis*) to be greater within the NTZ than in surrounding waters (Howarth *et al.*, 2011). Age, size and the biomass of adult scallops were also found to be greater with the boundaries of the NTZ. However, in agreement with the findings presented here, Howarth *et al.* 2011 were unable to detect a statistically significant difference in the abundance of adults of either species. It should also be noted that the reported site differences in their study cannot be attributed with any degree of certainty to the protected status of the NTZ because of a lack of sufficient temporal and spatial controls (see Underwood, 1994).

The Photographic Survey Technique

Photographic techniques are likely to underestimate true abundance to a greater extent than dive surveys. Indeed, the fact that *P. maximus* typically recesses into the substrate could mean that photographic techniques are not suitable to determine absolute abundance in this species reliably. Nevertheless, the photographic technique developed in this study produced comparable results, in terms of density estimates, to those of Howarth *et al.* (2011) who conducted a series of dive surveys in the NTZ at a different time of year. For example, density estimates for *P. maximus* taken from the NTZ in 2010 (the only area for which there is comparable data) were only marginally lower than those published by Howarth *et al.*; 0.05 m^2, presented here, against 0.06 m^2. However, differences in density estimates for *A. opercularis* within the NTZ were greater. This was unexpected as *A. opercularis* does not recess into the ground to the same extent as *P. maximus* and would be expected to be more reliably identified. *A. opercularis* is more mobile than *P. maximus* and it is possible that differences in abundance between the two studies reflect differences in distribution associated with the time of year sampled.

Conclusion

The large area of scallop grounds surveyed in this study, split across two replicate reference areas, permits the construction of robust statistical models. As with other protected areas circumscribing commercial scallop grounds, the NTZ within Lamlash Bay is likely to require further time before its effects on population abundance becomes apparent (see Murawski, 2000; Stokesbury *et al.*, 2002; Beukers-Stewart *et al.*, 2005). The data collected during this initial phase of the study do however provide a suitable baseline, complete with replicate control sites, to test the future performance of the NTZ. Photographic images collected during this study also include data relevant to the identification and enumeration of other large epifaunal species should their analysis be required. Whilst the photographic technique presented here allows a large number of quadrats to be surveyed comparatively easily, increasing statistical power, it does have limitations, and it should be noted that this technique is unable to provide reliable size estimates of individuals or indentify smaller scallop spat reliably. Data relating to scallop size and the abundance of scallop spat within and immediately outside the Lamlash Bay NTZ are available (see Howarth *et al.* 2011), and may continue to be collected, and it is likely that the comparison of both datasets will be informative as the study proceeds.

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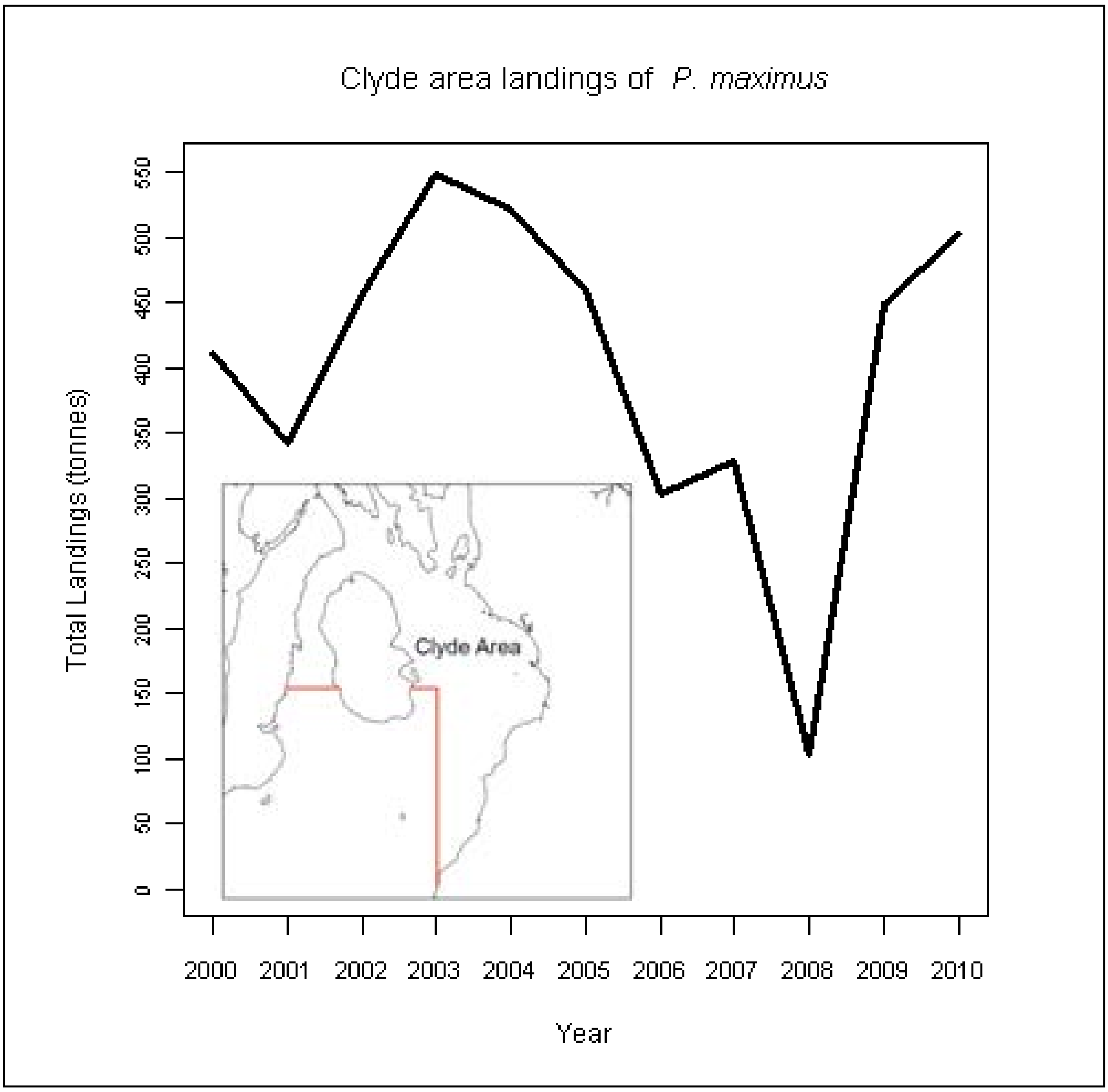

Figure 1: Total weight of *P. maximus* landed by UK vessels into Scotland from the three statistical rectangles that encompass the Clyde fishery (see inset) between 2000 and 2010 (Marine Scotland Science data, 2011).

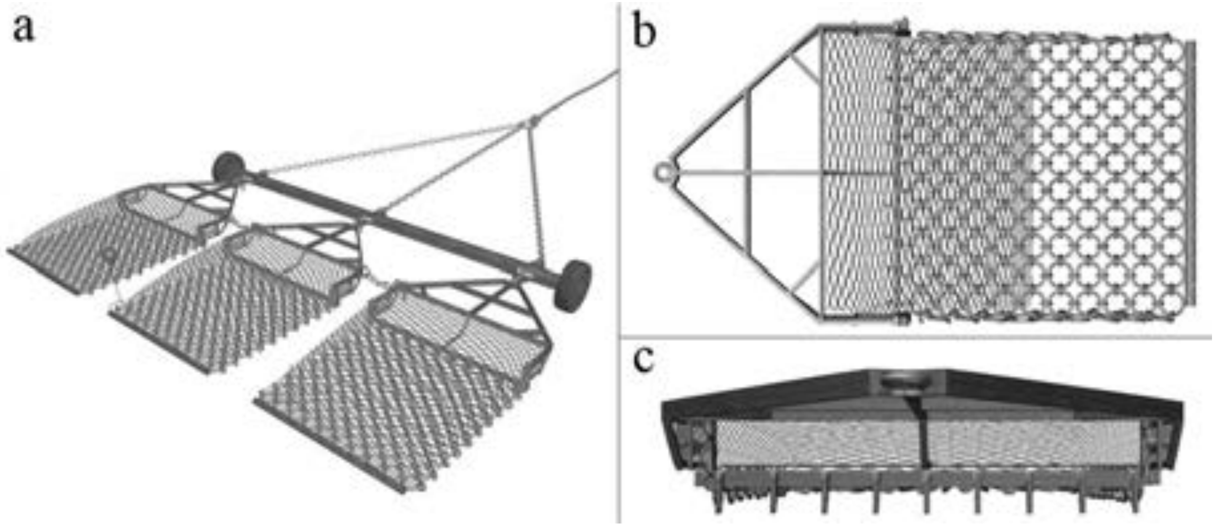

Figure 2: The “Newhaven dredge” commonly used in the UK commercial scallop fishery. Views show: (a) an angled view of a 3-dredge-a-side system and tow bar (b) the steel rings of the collecting bag (top elevation) and (c) the spring-loaded toothed bar (front elevation).

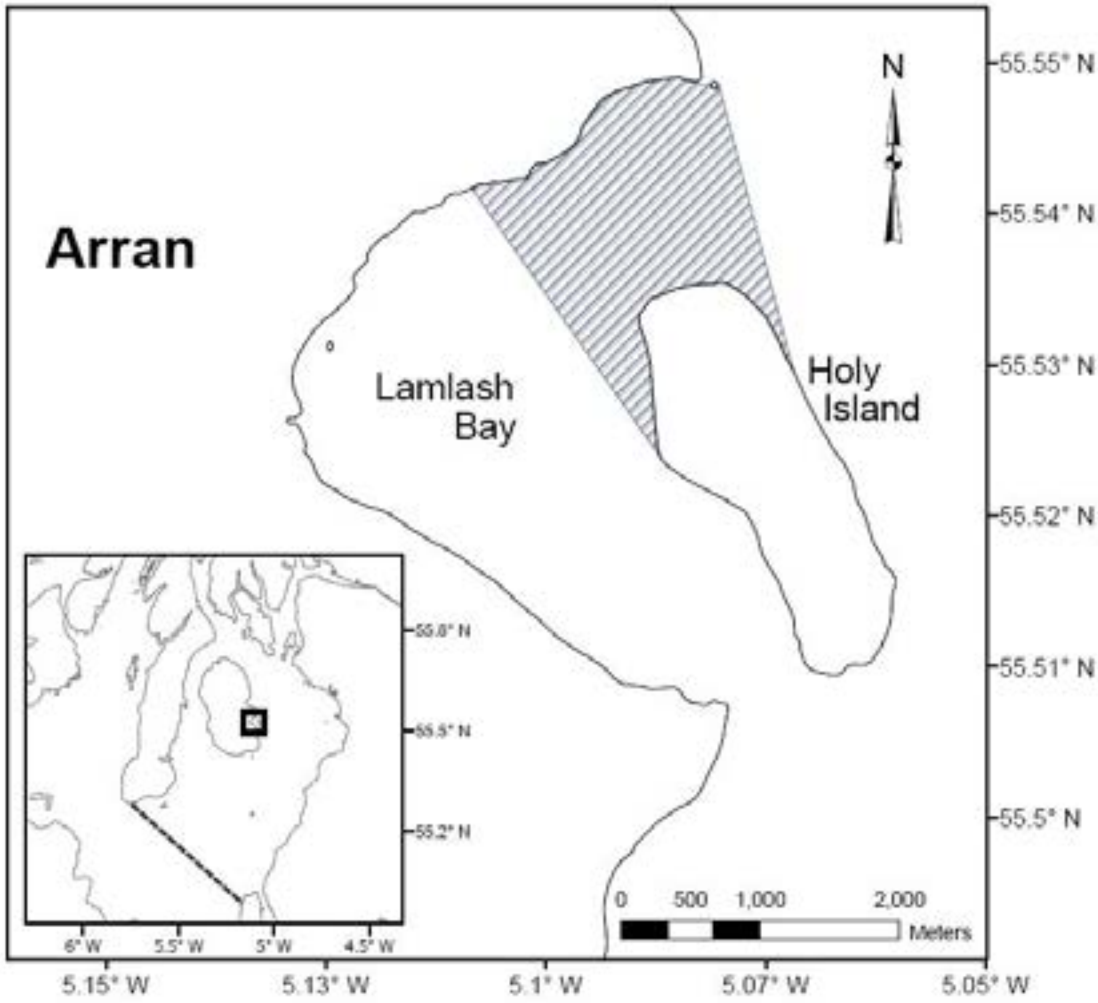

Figure 3: Lamlash Bay and the 2.65 km^2 No Take Zone (hatched area). Inset: the Firth of Clyde and Arran showing the boundary to the inner Firth of Clyde (dashed line) and the position of Lamlash Bay (solid rectangle).

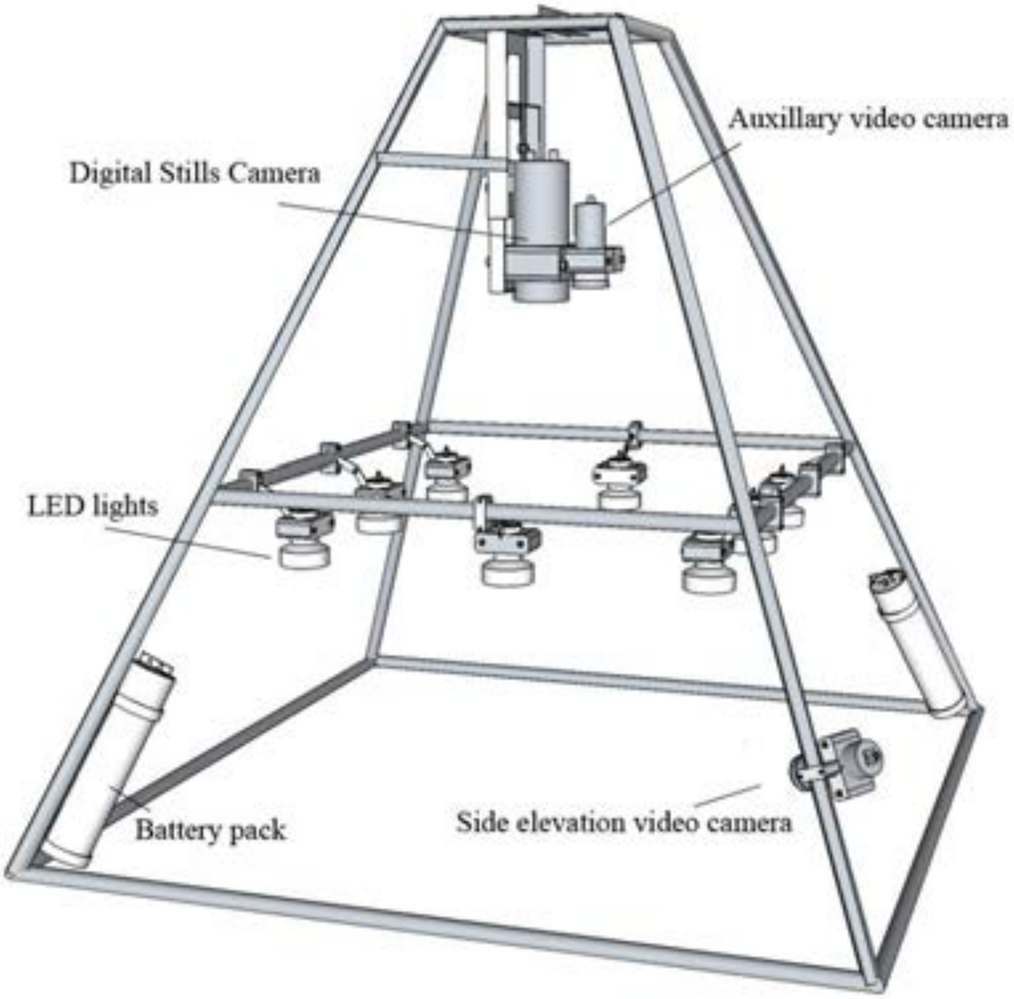

Figure 4: Schematic diagram of the camera drop frame developed by Marine Scotland Science and used throughout the study.

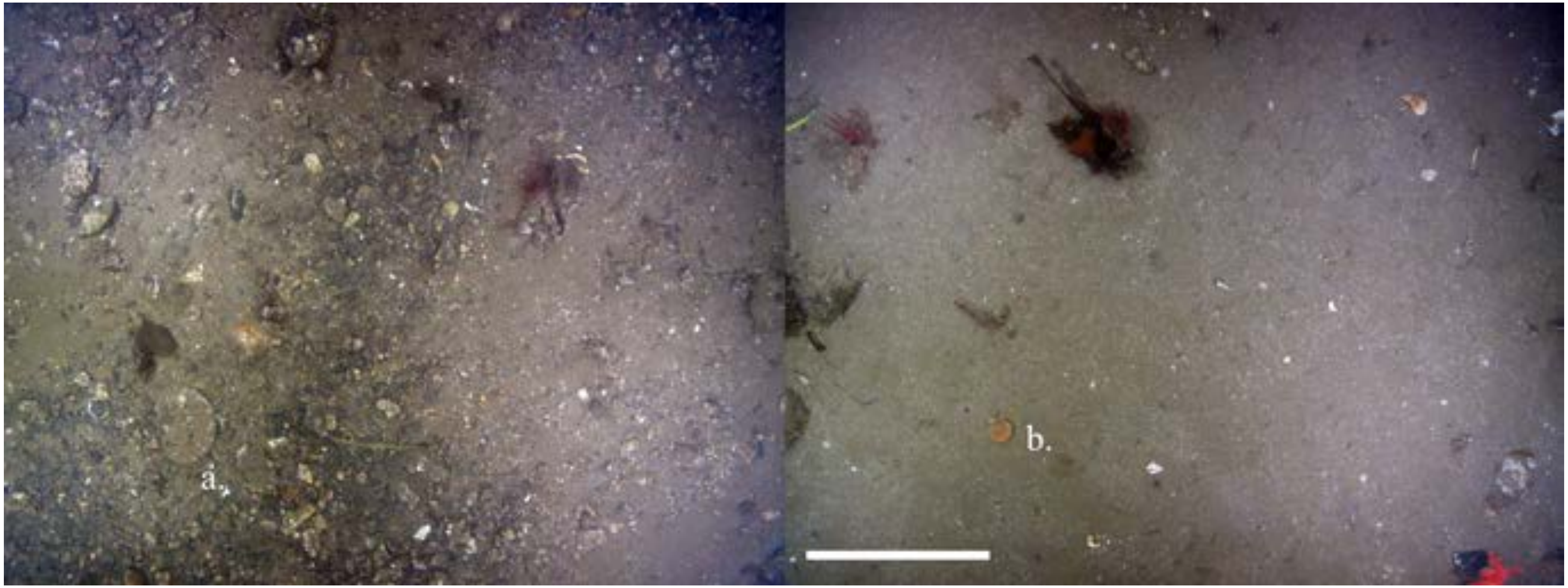

Figure 5: Two quadrat images taken during the 2009 survey showing a).the great scallop, *Pecten maximus* and b). the queen scallop, *Aequipecten opercularis*. The scale bar shown is approximately 40 cm in length.

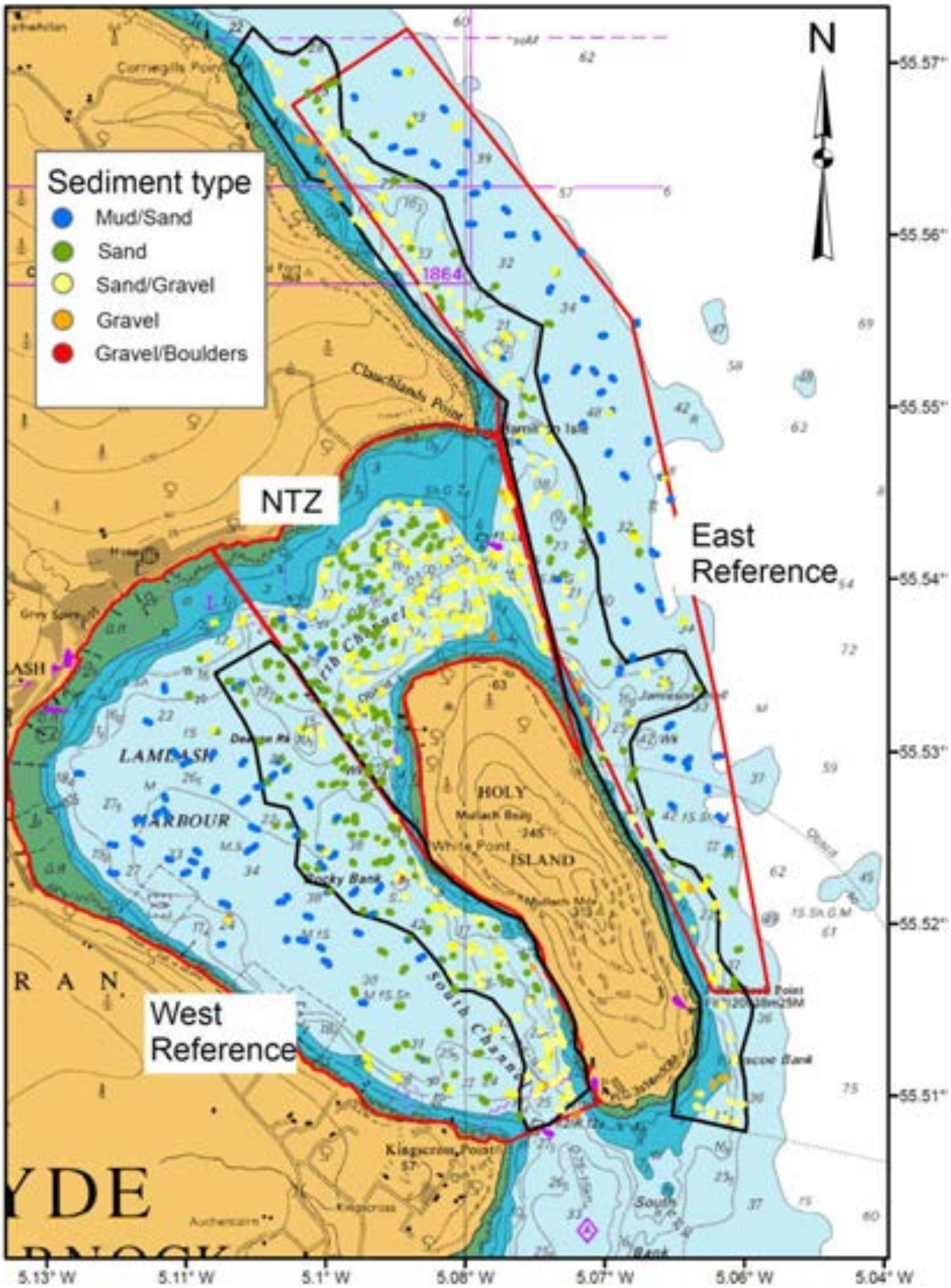

Figure 6: A sediment map of Lamlash Bay and surrounding waters to the east. The boundaries (red line) of the No Take Zone and two reference areas surveyed in the 2009 survey are shown. Both reference areas were redrawn to exclude mud substrates in the 2010 survey (black line).

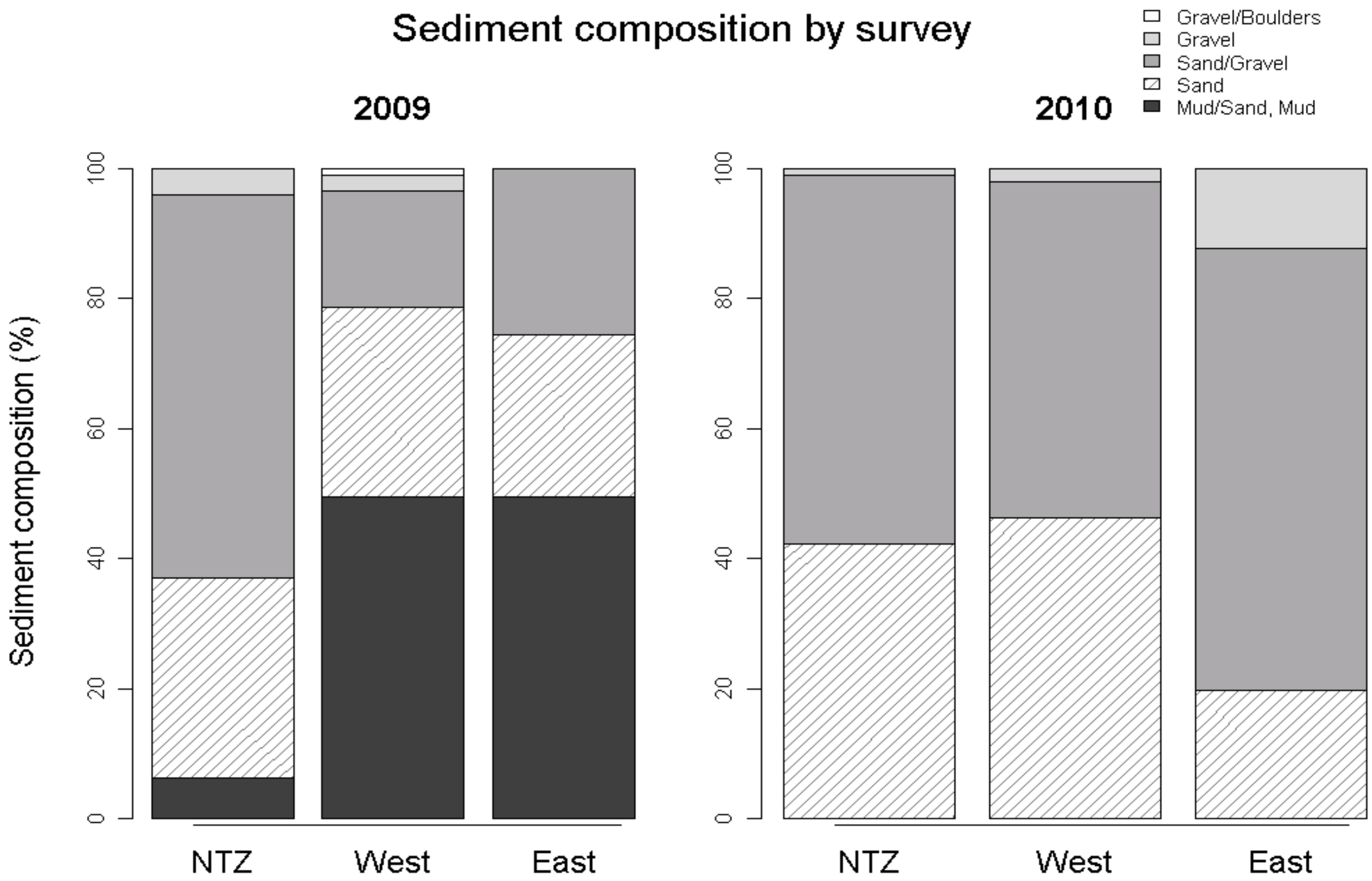

Figure 7: Percentage composition by quadrat of sediments in the Lamlash Bay NTZ and the west and east reference areas as observed during the 2009 and 2010 surveys.

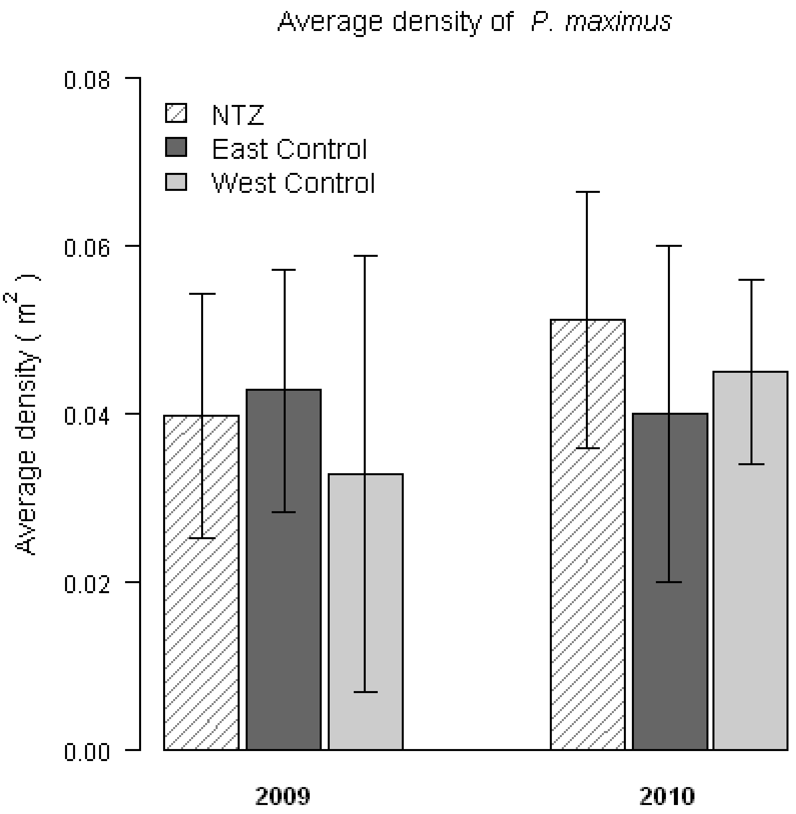

Figure 8: The mean density of great scallops, *P. maximus*, within the NTZ and the two reference areas in 2009 and 2010. *Error bars* represent ± 2 S.E.

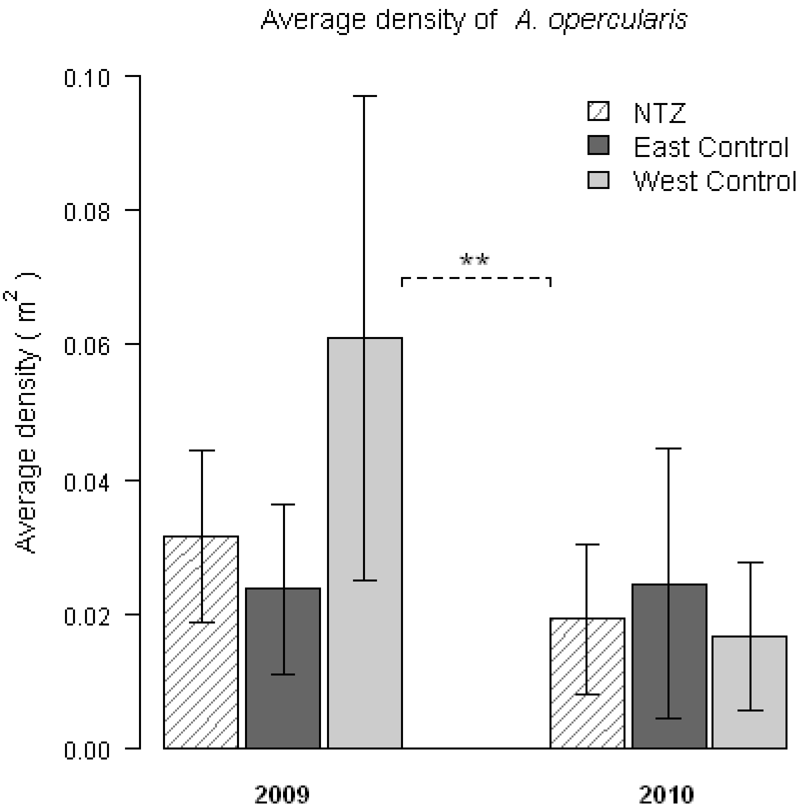

Figure 9: The mean density of the queen scallop, *A. opercularis*, within the NTZ and the two reference areas in 2009 and 2010. ** denotes a significant effect of year. *Error bars* represent ± 2 S.E.

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