Report on Razor Clam Surveys on Tarbert Bank

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Report on Razor Clam Surveys on Tarbert Bank

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Executive summary

This report describes a survey carried out on Tarbert Bank in 2023 to estimate the densities and sizes of razor clams, *Ensis siliqua* and *Ensis magnus*. The survey was conducted as part of the Scottish Government's electrofishing scientific trial (Scottish Government, 2017). A combination of commercial electrofishing rig and towed video was deployed using the fishing vessel 'Skye'. The video recordings were subsequently analysed for the number and sizes of razor clams observed on the surface of the seabed following passage of the electrofishing equipment. The count data were converted to area densities (numbers of razor clams m^{-2}) in three size classes (small < 100; medium ≥ 100 and < 150; large ≥ 150 mm shell length) based on estimates of the swept area.

Ninety-five tows were completed down to 22.5 m water depth (below sea surface). The maximum depth which could be surveyed was determined by the lengths of the electrofishing cables on the vessel, rather than the video cameras which are equipped with 100 m of cable. Fifty-five of the tows were conducted to the north of latitude 56ºN and forty tows to the south. The importance of this division is that under the Scottish Government's electrofishing scientific trial, fishing for razors is only permitted north of this division so the southern sector has not been fished for around five years. It was hoped that surveying the fished and presently unfished sectors would provide an interesting comparison. Surveying commenced on 16 February 2023, but sea conditions then deteriorated. Surveying re-commenced on 25 February and continued until 3 March 2023. In addition, a day was spent conducting a catchability experiment on 4 March 2023.

The equipment worked well with up to 15, but typically around 12 video tows completed each day. Image quality on the recorded video was clear and detailed, allowing identification and measurement of objects on the seabed. Fishing vessel 'Skye' has been built with electrofishing in mind and several features, such as the aft derrick and raised platform, made deploying and recovering the electrofishing and video rigs especially easy and safe. The cabin is spacious, providing plenty of room for the recording equipment and good visual access to the chart and depth plotters.

During the survey water temperatures were between 8.4 and 8.9°C and salinities between 33.7 and 34.2. Average towing speed was 3.7 ± 0.9 m min^{-1} (mean ± std

dev) so that most of the exposure times were longer than 30 seconds. Estimated swept areas averaged 93 ± 27 m^2 (mean ± std dev). From the video recordings 14,563 individual *E. siliqua* were identified and 12,350 measured. Low numbers of *E. magnus* (formerly *Ensis arcuatus*) were also noted in areas of coarser sediment with 570 being measured.

Considering all sizes of *E. siliqua,* the average density was 1.57 m^{-2} ± 0.11 (mean ± SE) with a maximum of 6.68 m^{-2}. The average density in the presently fished area (north of latitude 56ºN) was 1.87 m^{-2} (± 0.17 SE) and south of 56ºN was 1.16 m^{-2} (± 0.11 SE). The commercial fishers tend to target *E. siliqua* which are longer than 150 mm as these fetch the highest price and mean densities for this size group were 0.82 ± 0.05 m^{-2} (mean ± SE) in the presently fished sector and 0.84 ± 0.10 m^{-2} (mean ± err) in the presently unfished sector. The size distribution of the razor clams north of 56ºN suggested the presence of three length modes while in the southern sector two modes were apparent. The size distributions in the southern and northern sectors were statistically different with larger *E. siliqua* being dominant in the presently unfished area, although at a lower average density. The spatial distribution of medium (≥100 mm and < 150 mm shell length) and small (< 100 mm shell length) *E. siliqua* was notably different between the areas north and south of 56°N. These size groups were recorded at higher densities in the presently fished area. For medium sized *E. siliqua*, the average density was 0.80 ± 0.12 m^{-2} (mean ± SE) to the north of 56°N and 0.26 ± 0.04 m^{-2} (mean ± SE) to the south. For small sized *E. siliqua*, the average density was 0.26 ± 0.06 m^{-2} (mean ± SE) to the north and 0.06 ± 0.02 m^{-2} (mean ± SE) to the south of latitude 56°N. Small sized *E. siliqua* were predominantly found at higher densities around the northern periphery of the bank. This notable spatial pattern could be related to local hydrodynamics, although a possible fishery effect cannot be ruled out.

There were no very clear trends relating *E. siliqua* densities to water depth although there was a tendency for higher densities of small and medium sized razors to be found on tows deeper than 18 m. This reflects their spatial distribution mentioned above. In contrast, *E. magnus* tended to be occur on deeper tows reflecting their preference for coarser shelly sediment which is found around the edges of the bank.

Other organisms seen on the videos included crabs (likely *Carcinus maenas*), hermit crabs (unidentified species), common starfish (*Asterias rubens*) and brittlestars (likely *Ophiura ophiura*). A few juvenile flatfish (probably dab or plaice) were observed and several sandeels (*Ammodytes* spp.) were seen especially on tows over finer sand. In contrast to the survey conducted in Largo Bay (Fox 2021), eider ducks (*Somateria mollissima*) were not observed in the area. The survey vessel skipper suggested that although this species was occasionally seen on Tarbert Bank, they were generally in low numbers.

Although in previous surveys the efficiency of the electrofishing equipment has been assumed to be high, this has not been scientifically confirmed under field conditions. A series of depletion experiments were conducted on the last working day to measure the proportion of razor clams which emerge with increasing electrical exposure time. For three of the replicates, the proportion of razor clams which emerged following the first 30 seconds stimulation was as low as 0.5 but for the remaining 15 replicates was above 0.75. On average 82.0% of the total razor clams emerged during the first 30 seconds of electrical stimulation, with 11.9% following the second stimulation and 0.1% following the third stimulation. Based on the estimated exposure times during the survey tows, average catchability should be at least 82%. Future surveys could use slightly slower towing speeds which should ensure catchability closer to 100%, although this would be at the cost of slightly less ground covered per unit time. Furthermore, based on fishers' anecdotal evidence, catchability is thought to be lower in cold water and repeating the depletion study during the summer months might show higher efficiency at the speeds used in the present survey.

The data collected on Tarbert Bank provides a baseline with which to compare *Ensis* densities and sizes from future surveys. Comparison between the presently fished and unfished sectors of the bank suggests that the fishery has resulted in a statistically significant reduction in the proportion of larger razors north of latitude 56°N. However, there may also be differences in the extent of optimal habitat and growth conditions between the two areas because both the maximum and average densities of *E. siliqua* seem to be lower in the unfished area. The finding that higher densities of small and medium size *E. siliqua* were mainly confined to the northern part of the bank may suggest an important role for local hydrography in determining recruitment dynamics.

Part 1 – Materials and methods

Introduction

The aim of this survey was to use a combination of electrofishing with towed video to assess the quantities and sizes of razor clams (*Ensis* spp.) on Tarbert Bank. This is one of a series of surveys in areas where razor clam harvesting is permitted under the Scottish Government's scientific trial on electrofishing (Scottish Government, 2017, 2019). Areas where commercial shellfish harvesting is permitted are also limited by hygiene regulations and waters are classified for this purpose by Food Standards Scotland (https://www.foodstandards.gov.scot/business-and-industry/industry-specific-advice/shellfish).

In addition, commercial razor clam harvesting is not permitted in some locations for nature conservation reasons, based on advice from NatureScot. Evidence from previous field surveys, and monitoring of the fishery, shows that even within the larger permitted fishing areas, the distribution of *Ensis* is patchy. Razor clams only occur in commercial densities in certain locations and fishers recognise specific areas or beds where fishing is worthwhile. Predetermined randomised surveys covering the whole of the production area are therefore unlikely to yield particularly useful information because much of the area is not suitable habitat. The present survey thus made extensive use of local fisher knowledge, as well as fishing location data collected by Marine Directorate (formerly Marine Scotland), to target the parts of the production area which have been regularly fished during the trial. For Tarbert Bank the latitude 56ºN divides the area into a northern part where electrofishing is permitted, and a southern part where it is prohibited. Additional tows were therefore conducted in the southern area for comparison purposes.

Materials and methods

Calibration of the video cameras

Surveys were conducted using the video equipment described in Fox (2017). Briefly, the equipment consists of three downward pointing cameras mounted on a sled which is towed behind a commercial electrofishing rig. For the Tarbert Bank work the original Sony video cameras were replaced with MacArtney Luxus cameras. Although the Sony cameras were cheap and had provided good service (Fox 2017, Fox 2018, Fox et al. 2019, Fox 2021), they had also not proven to be particularly robust with seawater ingress leading to regular failures. Furthermore, the Sony cameras were no longer available on the market, so an alternative had to be found.

The Luxus cameras use the same imaging chip, are better sealed (rated down to 200 m depth), are still relatively inexpensive and could be mounted on the video rig with minor modifications to the mounting brackets. Because new cameras were used in the video rig, it was necessary to recalibrate them using the Scottish Association for Marine Science (SAMS) seawater testing tank prior to the survey. Processing of the video prior to estimating clam sizes involves correcting the video images for camera lens distortion and combining the three separate video feeds to give a composite picture of the video swath. The conversion factor from video pixels to millimetres for the new cameras was estimated to be 1 px = 1.2 mm.

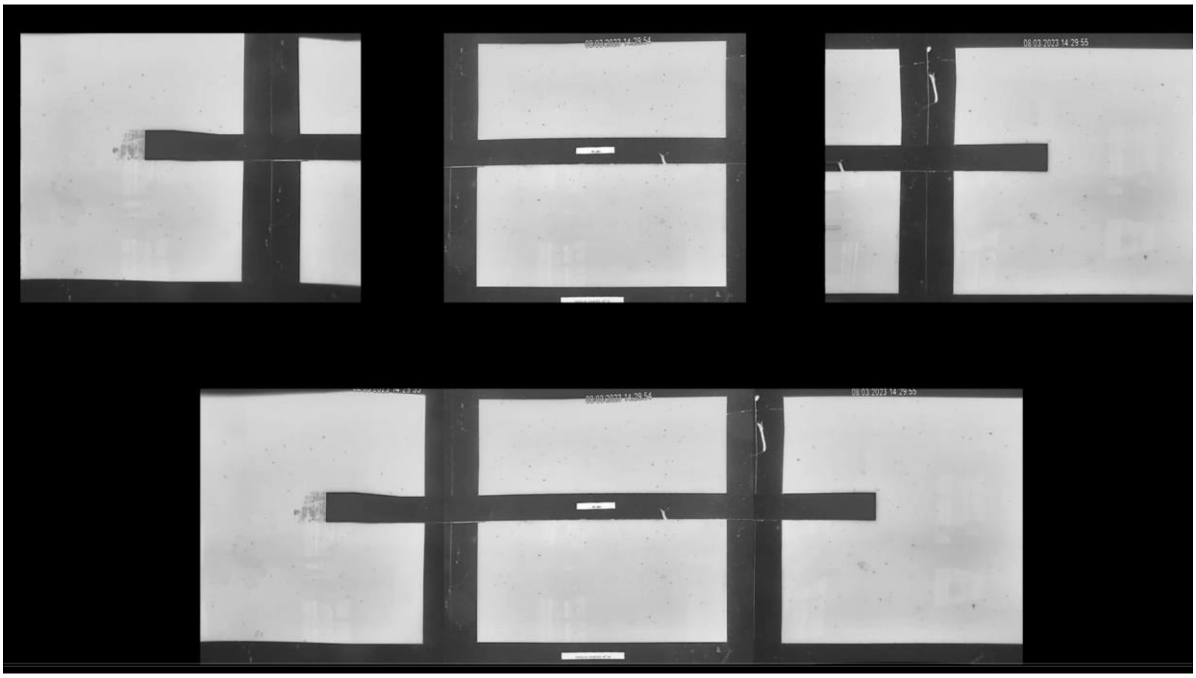


Figure 1: Reconstructed video swath from the three downward facing video cameras. The individual feeds imaged in the SAMS test-tank are shown in the upper row and the combined image with a real-world width of 1.5 m in the lower panel.

As a further check on the accuracy of reconstructing object sizes from the video, two 150 mm long, plastic blocks were recorded at various locations within the field of view in the test tank. Forty measurements of the blocks at different locations in the field of view were reconstructed from the post-processed video. Compared to the known calibration block length, the reconstructed lengths showed a small positive bias of 3 mm. This probably arises because of the thickness of the blocks which raises them about 1 cm above the test tank floor, and thus above the square calibration targets which are flat and laid underneath the camera rig runners. After applying a 3 mm bias correction, all reconstructed calibration block measurements were within 9 mm of the true block lengths (the mean of the reconstructed measurements = 148 mm, std dev = 4.2 mm, n = 40). The distribution of reconstructed lengths did not differ significantly from a normal distribution (Kolmogorov-Smirnov D = 0.117, p = 0.601) giving a relationship between the 95% confidence interval around a mean against number of objects measured as shown in Figure 2.

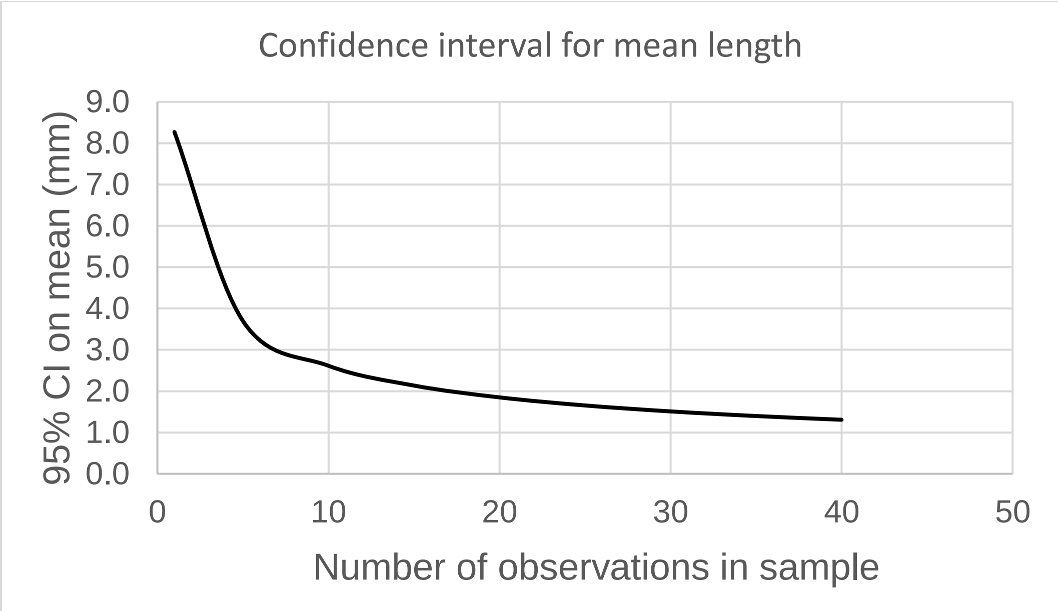


Figure 2: Relationship between the 95% confidence interval about mean reconstructed length and the number of observations for a 150 mm long object.

The impact of varying object distance was tested and reported in Fox (2017) for the original Sony cameras. It was concluded that major errors in reconstructed lengths of individual razor clams were unlikely, unless there were large undulations (>5 cm) in the seabed leading to substantial variations in the distance between a camera and the target. Although this source of error was not re-investigated with the MacArtney cameras, the result is expected to be similar following lens distortion correction. The height of sand ripples in the field will generally be smaller than 5 cm, so this is not expected to be a source of significant error in reconstructed object lengths. Individual reconstructed razor clam lengths from field collected video are therefore expected to have an accuracy of ± 9 mm of their true length with the accuracy of mean estimates improving to ± 2 mm (95% confidence interval) when more than 20 observations are included the calculation.

Tarbert Bank field survey

Tarbert Bank lies between the islands of Jura and Colonsay on the Scottish west coast (Figure 3). The permitted area where electrofishing may take place covers waters right around Colonsay, but Tarbert Bank has been a focus of electrofishing effort within this area in recent years.

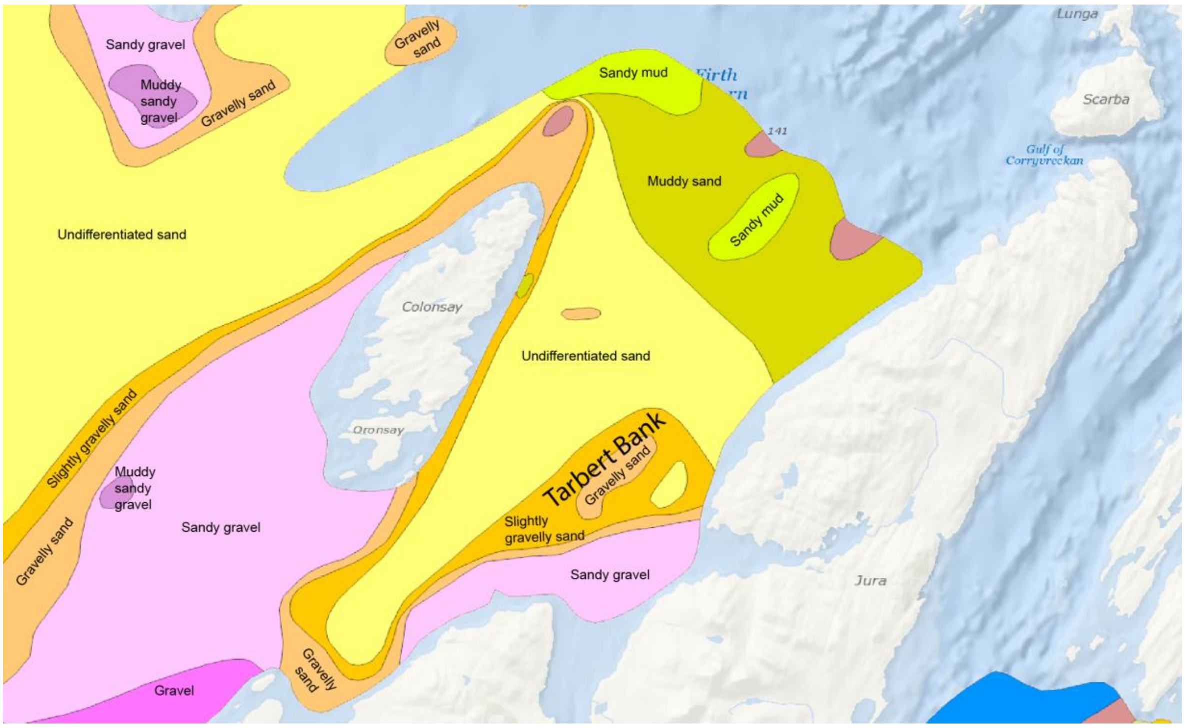


Figure 3: Surficial sediments on Tarbert Bank and area surrounding Colonsay (Source: BGS Seabed Sediments 250k dataset). The sediment divisions are primarily based on particle size analysis (PSA) of both surface sediment samples and the uppermost sediments taken from shallow cores classified according to the modified Folk triangle classification (Folk, 1954, Journal of Geology, Vol. 62, pp 344–359). The modified Folk diagram and classification used by BGS differs from that created by Folk (1954) in that the boundary between "no gravel" and "slightly gravelly" is changed from trace (0.05%) to 1% weight of particles coarser than -1Ø (2 mm).

Nearly all the recorded commercial electrofishing has occurred in depths shallower than the 20 m depth contour, and as previously mentioned is restricted to north of latitude 56°N (Figure 4). The bank itself curves slightly towards the south and comprises shallow sandy sediments above 15 m charted depth, dropping away to deeper areas to the northwest and southeast. The area shallower than 15 m is around 5.6 km in north-south direction, and 1.2 km at its widest point. The bank is slightly narrower comparing the northern to the southern sections.

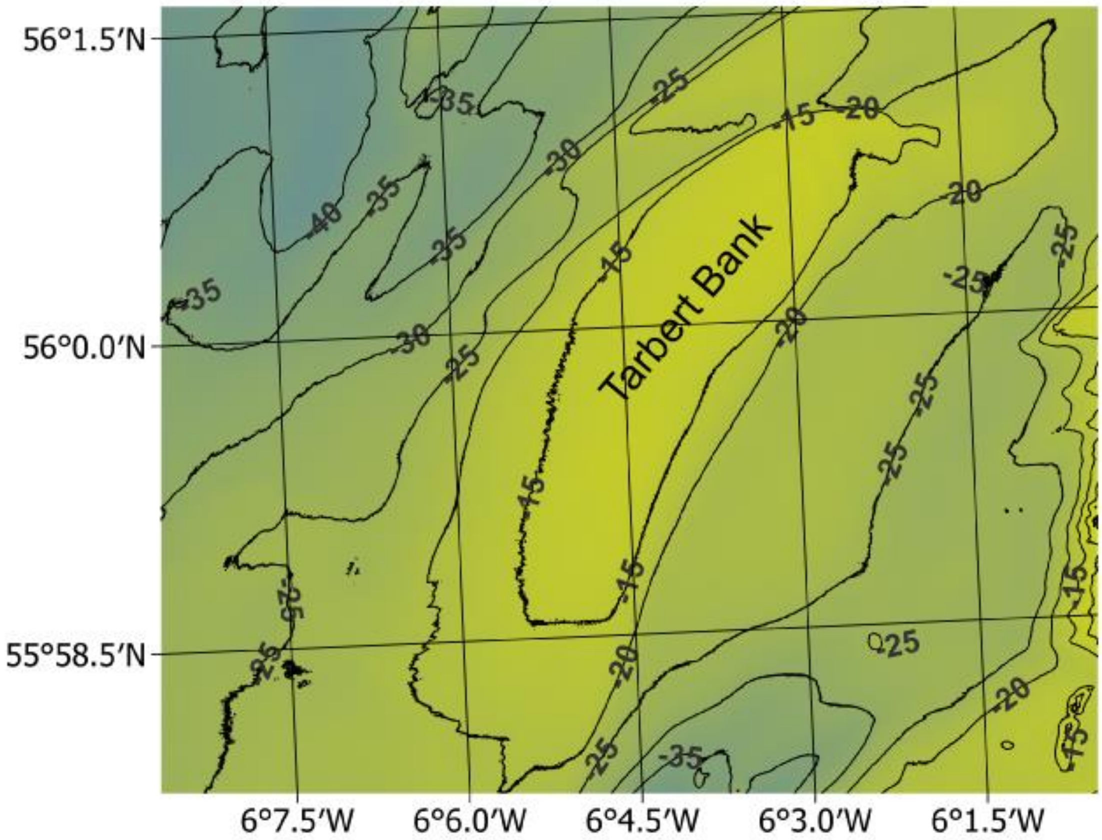


Figure 4: Tarbert Bank bathymetry based on S-44 hydrographic standard, UK Hydrographic Office 2010 as part of their Safety of Life at Sea (SOLAS) project. Depth contours are below chart datum while the solid red line encompasses the area where nearly all the electrofishing activity has taken place (Source: Marine Scotland).

The survey was conducted from the fishing vessel ‘Skye’ (CN450; Scottish Fishing, Campbeltown) skippered by Mr. Craig Barrett. The vessel is new and was built with several features to facilitate electrofishing. These include the general deck layout with the electrode cable connectors conveniently located at the stern, an aft lifting derrick and a stern platform with clips for securing the electrofishing bar when in transit (Figure 5).

Figure 5: Aft deck of fishing vessel ‘Skye’ showing the raised platform with electrical cables, electrode spreader bar and the towed video rig stowed during passage.

The fishing operation involves dropping an anchor and then reversing the vessel whilst paying out a cable until the vessel is between 150 and 200 m from the anchor. ‘Skye’ fishes with a clump weight and therefore relies on a combination of tide and wind to set the direction of the tow. Once the vessel has settled the clump was lowered, the electrofishing gear set on the seabed and the vessel then slowly warped towards the anchor. This means it was not possible to follow a pre-designed survey plan because the exact positions which can be worked are continually varying depending on the changing state of the tide and wind. We therefore placed tows aiming to give a comprehensive coverage of the area. Recovering and moving the anchor is the most time-consuming part of the operation and will reduce the number of tows which can be completed in a day considerably. To reduce the amount of relocation time we collected two or three video tows along each anchor line with tows being spaced at least 50 m apart.

The electrofishing rig consists of a 5 m wide plastic spreader bar fitted with three pairs of brass electrodes, each 2.6 m in length with 1 m separation between positive and negative electrodes. The video rig was towed 3 m behind the spreader bar of the normal commercial electrofishing rig used on ‘Skye’. Power was supplied using an inverter box as 24 V AC at around 50-80 amps per electrode pair in line with the electrofishing equipment regulations stipulated by the Scottish Government for use in the trial fishery. All experimental fishing took place under a specific survey derogation issued by Marine Scotland Access to Sea Fisheries. Once correct deployment of the gear was confirmed (Figure 6), the power to the electrofishing rig was turned on and the survey tows commenced. Maximum fishing depth was around 22 m due to the length of electrode cables available with deeper locations being surveyed at low water. The fishery rarely works areas deeper than 20 m due to the bottom-time limits on air-based SCUBA diving.

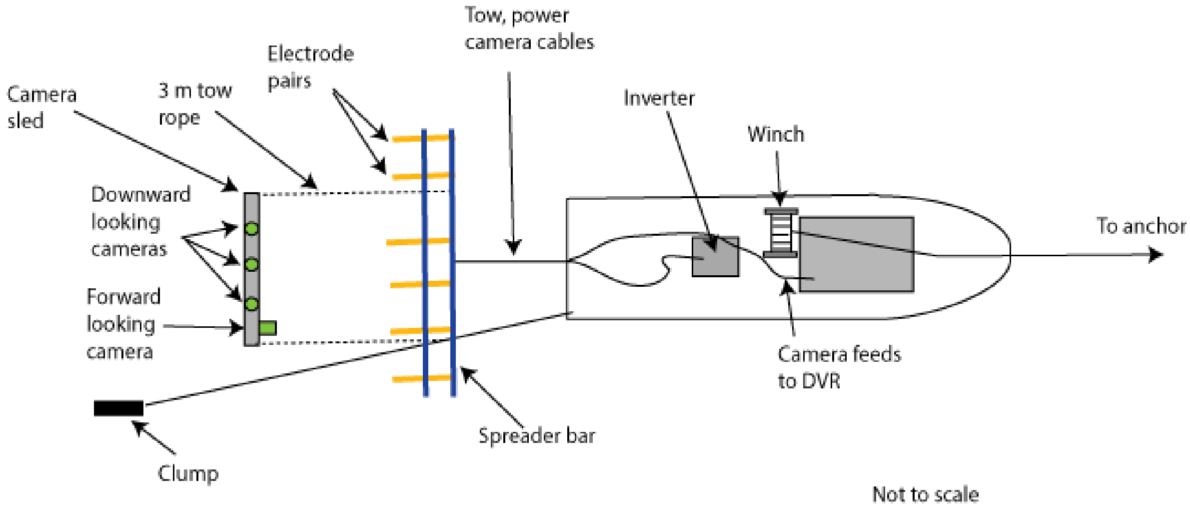


Figure 6: Diagram illustrating the electrofishing gear and towed camera sled.

Video from the three downward facing cameras was monitored continuously during the tow and recorded using a digital video recorder (Hawk D1/960H AHD RF3089, RF Concepts, Belfast UK). Water column parameters (temperature and salinity) were recorded daily from the surface to the seabed using a CastAway CTD (SonTek, San Diego, California).

Post fieldwork analysis of recorded videos

Recorded videos were downloaded as .avi files and processed using the Matlab scripts described in Fox (2017), but with the lens distortion calibrations updated for the MacArtney Luxus cameras based on the test-tank calibrations undertaken just before the surveys. The lengths of razor clams on the processed video were recorded manually using the interactive Matlab program which is also detailed in Fox (2017). Additional notes were made of any other organisms seen, such as crabs and fish. All videos were reviewed by the same analyst (Mr Lars Brunner).

To convert the counts to area-based densities, estimates of tow length are required. These were calculated from the start and end positions of each tow recorded from the vessel's GPS chart plotter. The distance between these two points was calculated using the Haversine formula.

The camera alignments and video processing were set up so that the total imaged swath was 1.5 m wide and thus the swept areas (m^2) were estimated as tow lengths multiplied by 1.5 (except for tows on day one of the survey where one of the camera connections failed and the swath width was consequently 1 m in width). Razor clams on the videos were assigned to one of five categories:

1 - whole *E. siliqua* lying flat on the seabed;
2 - *E. siliqua* lying flat on the seabed but overlapping the edge of the video frame so that only part of the shell was visible;
3 - *Ensis* tops where the clam had not fully emerged from the sediment and species could not be indentified;
4 - whole *E. magnus* lying flat on the seabed;
5 - *E. magnus* lying flat on the seabed but overlapping the edge of the video frame so that only part of the shell was visible.

For Categories 2 and 5 it was assumed that each count would represent half an individual contribution to the overall density (since on average half an individual count would lie in the adjacent area outside the field of view). The length data from Categories 2 and 5 were not used further. For Category 3, each record was counted as one individual but the total count of category 3 objects on a tow apportioned as to *E. siliqua* or *E. magnus* in the ratio of Categories 1:4 in the tow (because it is not possible to reliably discriminate between the species when only the top is visible). The length data for Category 3 were not used further.

Estimation of *Ensis* densities on Tarbert Bank

To obtain the total count of *E. siliqua* (all sizes) on tow $_i$:

$$E.\ siliqua_i = \text{count cat } 1_i + \ldots \\ \text{count cat } 2_i / 2 + \ldots \\ \text{count cat } 3_i * \text{count cat } 1_i / (\text{count cat } 1_i + \text{count cat } 4i)$$

Equation [1]

where count Cat 1_i is total number of whole *E. siliqua* in tow $_i$; count Cat 2_i is the total number of *E. siliqua* partially within the video frame in tow $_i$; count Cat 3 is the total number of partially emerged Ensis in tow $_i$; and count Cat 4 is the total number of whole *E. magnus* in tow $_i$.

When considering the counts and densities of *Ensis* above a certain length, the count of Category 2 and 3 objects on a tow is meaningless (because the total length of *Ensis* which are partially within the video frame or partially emerged is not known). The total count above a size limit was thus estimated based on the assumption that the proportional distribution between the size fractions among the different object categories would be the same. Therefore, the total count of *E. siliqua* above size $_z$ on tow $_i$ is given by:

$$
\begin{aligned}
E.\ siliqua_{>z,i} = {} & \text{count cat } 1_{>z,i} + \ldots \\
& ((\text{count cat } 2_i / 2) * (\text{count cat } 1_{>z,i} / \text{count cat } 1_i)) + \ldots \\
& ((\text{count cat } 3_i * \text{count cat } 1_i / (\text{count cat } 1_i + \text{count cat } 4_i)) * \ldots \\
& (\text{count cat } 1_{>z,i} / \text{count cat } 1_i))
\end{aligned}
$$

Equation [2]

Density estimates for *E. siliqua* (nos m^{-2}) were then calculated by dividing the total counts from tow $_i$ by the estimated swept area of tow $_i$ (m^2). Density estimates were mapped using QGIS (version 3.28.4) and other statistical calculations performed using R (version 4.2.2).

Similarly, the total count of *E. magnus* on each tow was estimated from Equation 3 but because this species is not normally harvested, length stratified counts and density estimates were not produced for this species.

$$
\begin{aligned}
E.\ magnus_i = {} & \text{count cat } 4_i + \ldots \\
& \text{count cat } 5_i / 2 + \ldots \\
& \text{count cat } 3_i * \text{count cat } 4_i / (\text{count cat } 1_i + \text{count cat } 4i)
\end{aligned}
$$

Equation [3]

where count Cat 4_i is total number of whole *E. magnus* in tow $_i$; count Cat 5_i is the total number of *E. magnus* partially within the video frame in tow $_i$.

Results

Water column

As expected, based on the strong tides around the bank the water column was largely well mixed although with a slight halocline at around 5 m depth on some days (Figure 7). Water temperatures were between 8.4 and 8.9°C and salinities between 33.7 and 34.2.

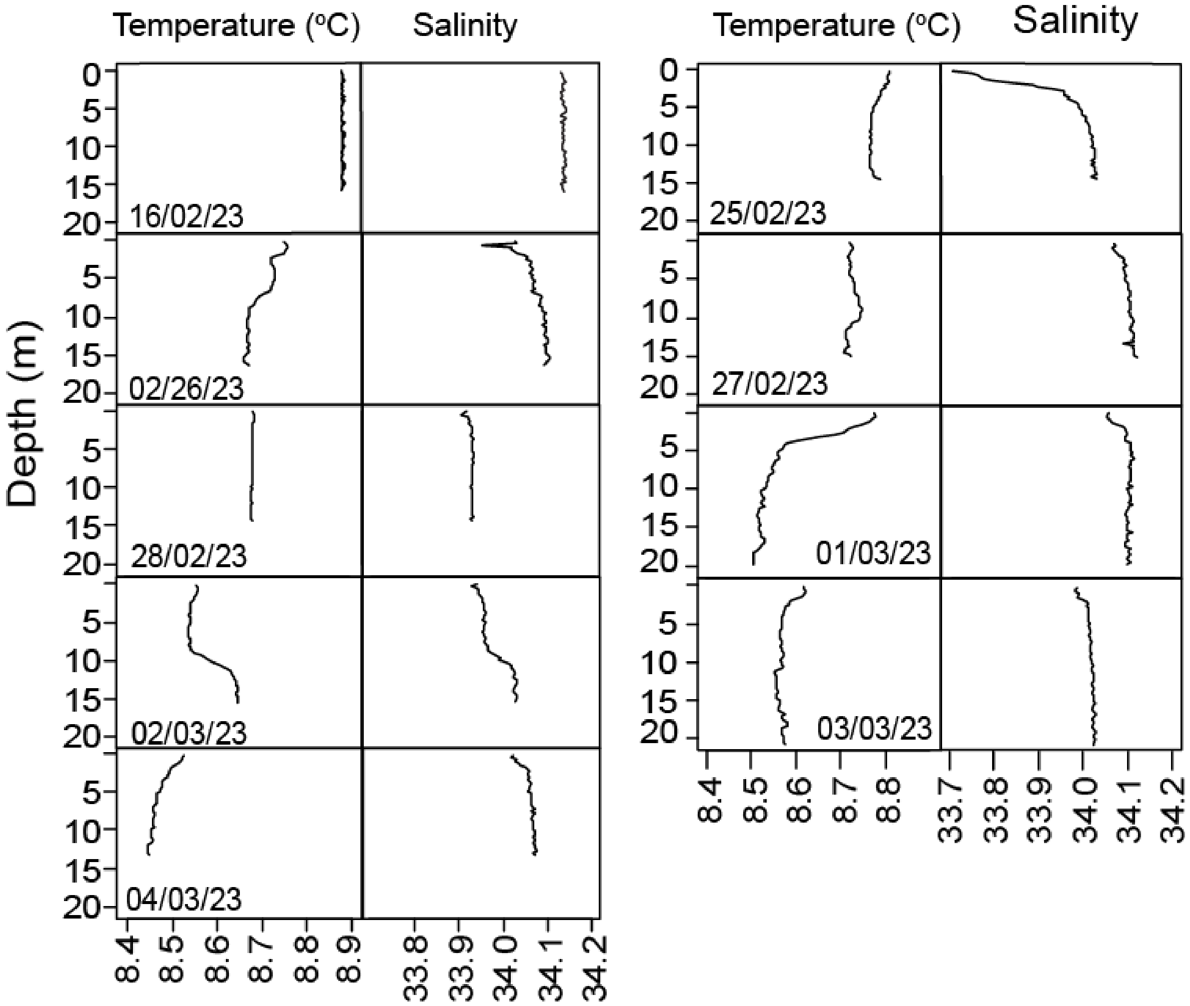


Figure 7: Water column temperature and salinity profiles.

Video tows

Summaries of the video tows are given in Appendix 1. A total of 95 tows were completed with 55 of these being north of latitude 56ºN and 40 being in the presently unfished area of the bank south of 56ºN (Figure 8).

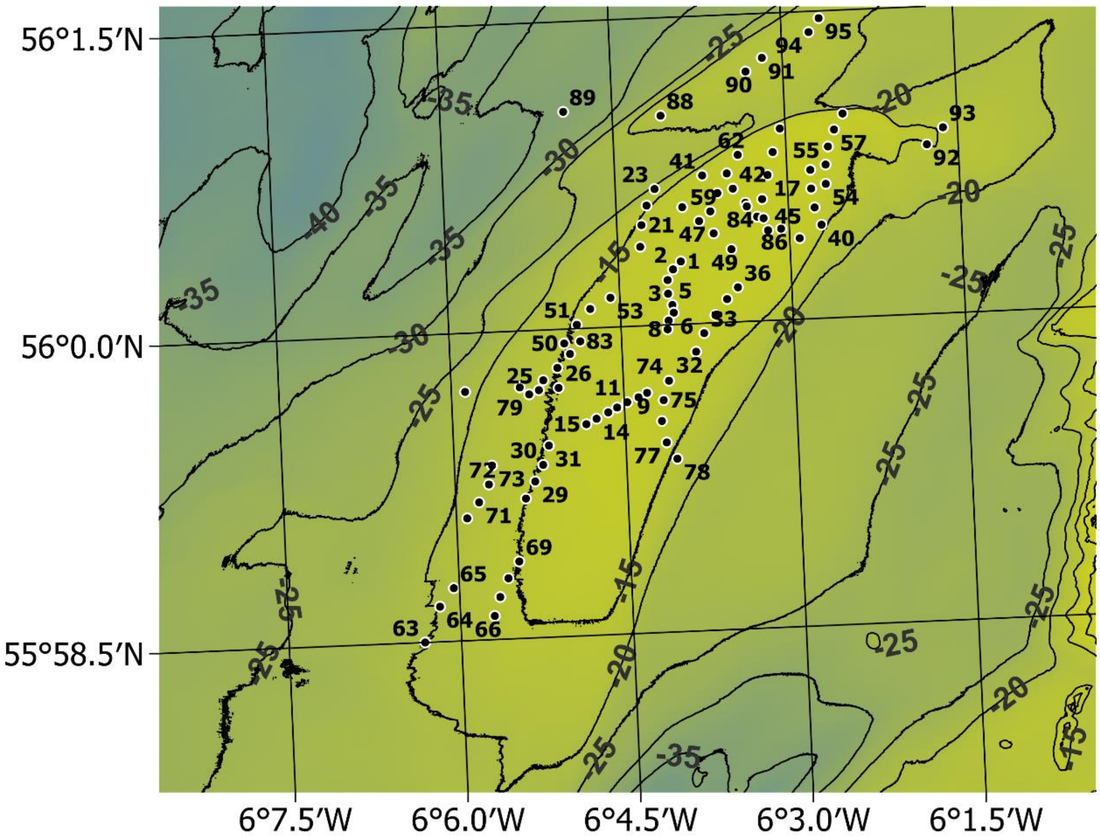


Figure 8: Mid-points of video tows on Tarbert Bank (labelled solid black dots). Contour lines are the water depths in metres below to chart datum.

The commercial razor clam diving operations tend to be restricted to relatively shallow depths, typically less than 18 m but 21 tows were conducted in deeper water down to 22.5 m (Figure 9). The aim was to see whether there are repositories of *Ensis* below the normal diving depths which might act as a reservoir supporting recruitment of young razor clams to the shallower waters.

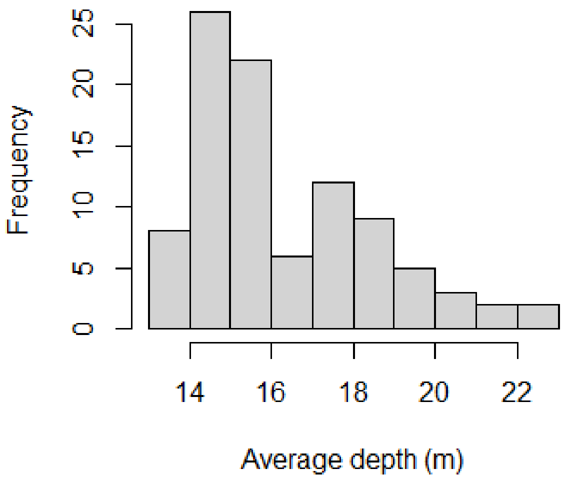


Figure 9: Average depths of the video tows. Note these are depths beneath the sea surface at time of sampling and not corrected to chart datum.

The video equipment worked well with the rig settling into the correct configuration on nearly all the tows at the first deployment. On a few occasions when there was a strong cross-tide the equipment became twisted and had to be re-set, but this did not cause any substantial delays or damage to the cameras or cables. The MacArtney Luxus cameras produced clear images even on the deepest tows allowing easy identification of razor clams resting on the sediment (Figure 10).

Figure 10: Example of image quality from stitching the three MacArtney Luxus camera feeds to generate a composite image equivalent to 1.5 m width on the seabed (tow 42, 27 February 2023 recorded in 15 m water depth). The trail marks left in the sand by the electrodes are also visible.

The mean tow duration was 17 minutes (± 2.7 std dev) with only a few tows having to be terminated early due to concerns about changing sea conditions (Figure 11a). The majority of tows were longer than 50 m (Figure 11b) which was the minimum distance recommended in Fox (2019) to produce cost-effective improvements in errors around mean density estimates. However, based on simulations it was also concluded that the expected 95% error of the true mean density should be as low as 10% when 30 or more individual tows are made in an area. In summary, the precision of the mean density estimates are likely to be more strongly influenced by increasing the number of video tows from an area, rather than substantially increasing the lengths of individual tows. However, towing speed is also an important consideration as it influences the length of time any area of the seabed is exposed to the electrical field during the tow (Figure 11c). Towing speeds varied between 1.6 and 5.4 m min^{-1} (3.7 ± 0.9 mean ± std dev) so that most of the exposure times were longer than 30 seconds (Figure 11d). Although it has always been assumed that the electrofishing technique is efficient, this has never been scientifically tested in the field. The relationship between electrical exposure time and razor clam emergence rates was therefore studied in a depletion experiment conducted on 4th March 2023 and described later in this report.

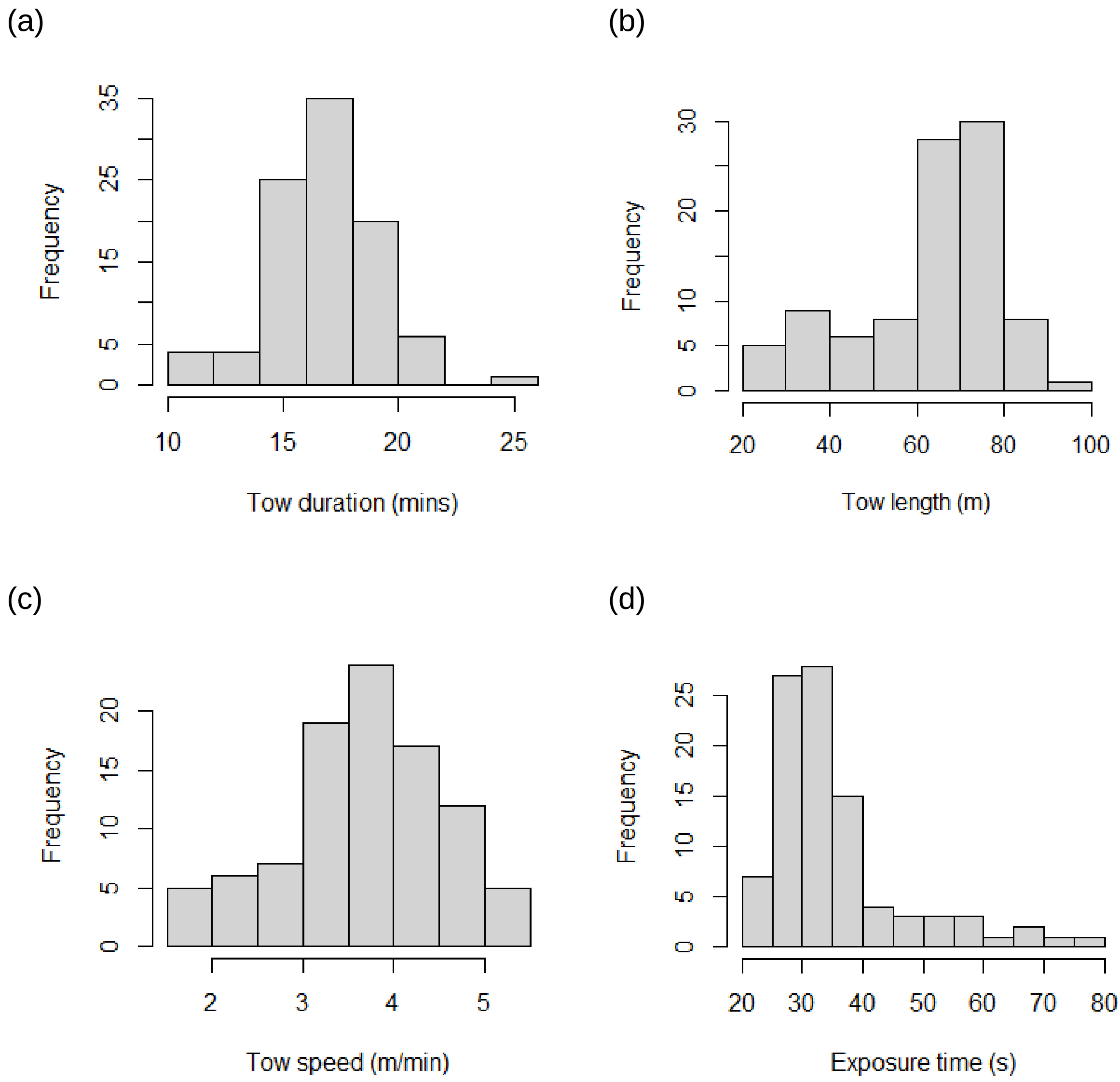


Figure 11: Histograms showing the distribution of (a) tow durations (mins); (b) tow lengths (m); (c) average tow speed (m min^{-1}) and (d) average exposure time to the electrical field (s).

The average swept area on the video tows was 93 ± 27 m^2 (mean ± std dev) with most tows being above the minimum 75 m^2 recommended by Fox (2019) to produce improvements in errors in mean density estimates (Figure 12).

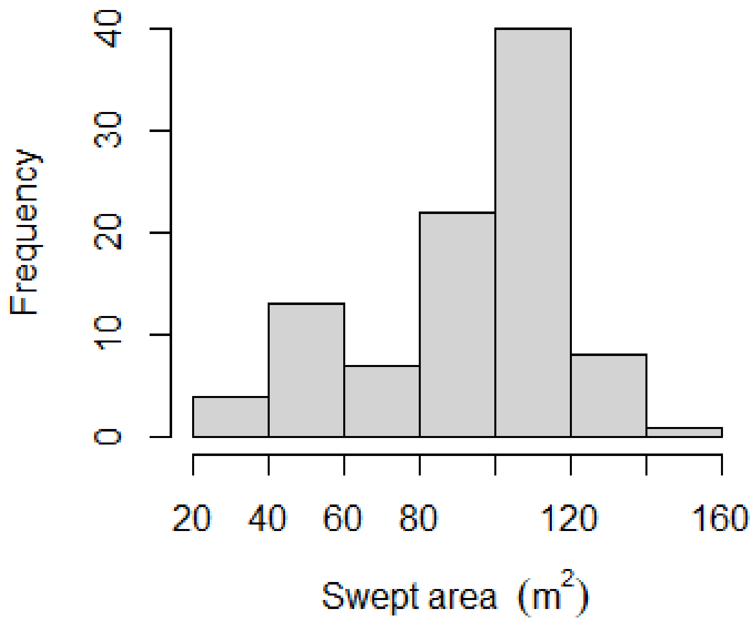


Figure 12: Distribution of swept areas across all the tows undertaken in the Tarbert Bank survey.

From the video observations, the sediments on the top of Tarbert Bank appear to consist of fine rippled sand mixed with ground shell fragments (Figures 13 a and b).

(a)

(b)

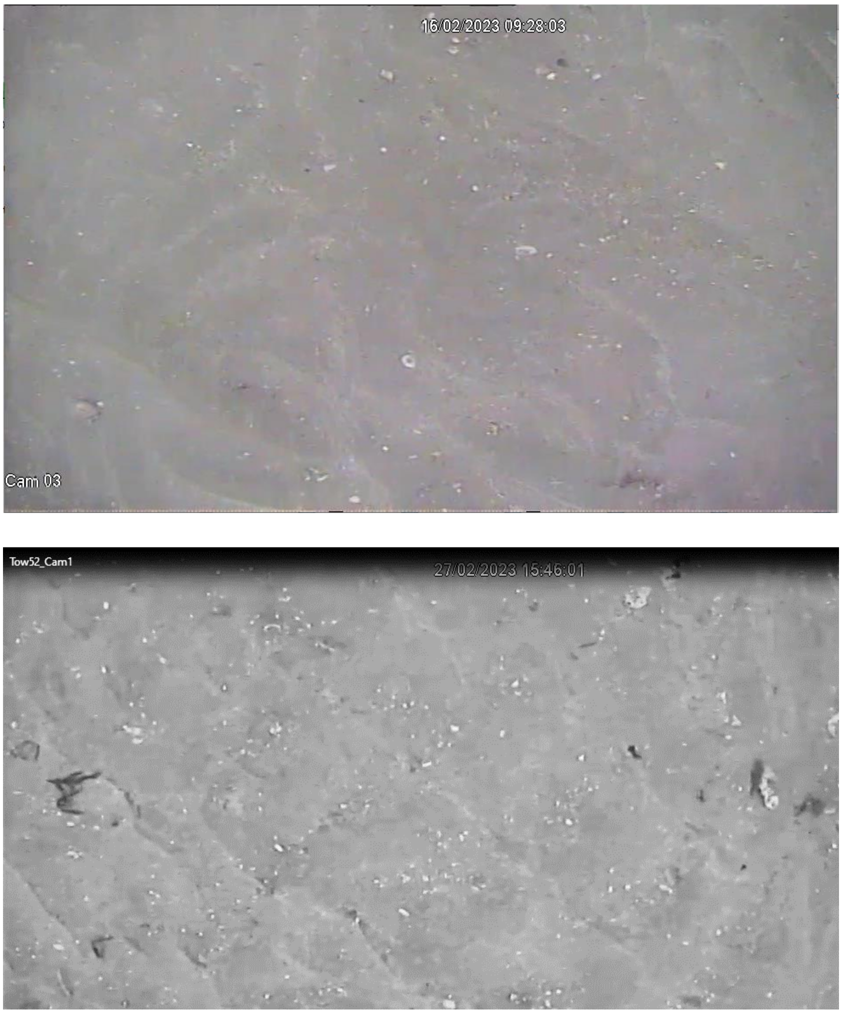


Figure 13: Seabed appearance on (a) Tow 1 on the top of the bank in 14.5 m water depth in the northern fished area (b) Tow 52 on the top of the bank in 16.5 m water depth in the southern unfished area.

Off the northern end of the bank the sediment appeared to be slightly coarser with more shell fragments (Figure 14a) whilst in the deeper water off the southern end of the bank the sediment again appeared to contain coarser fragments of shell compared with the shallower tows (Figure 14b).

(a)

(b)

Figure 14: Seabed appearance on (a) Tow 91 off the northern end of the bank in 19 m water depth with an emerged Ensis magnus (b) Tow 63 off the southern end of the bank in 22.5 m water depth.

Razor clam emergence and depth

The mean percentage of razor clams which were partially emerged was 9.8 ± 5.4 % (mean ± std. dev.) of the total razors observed on the videos (Figure 15a). There was no obvious relationship between percentage partial emergence and mean exposure time (Figure 15b) or water depth at the time the videos were recorded (Figure 15c). There did appear to be some relationship with mean *E. siliqua* densities (Figure 15d) but this could be artefactual with the apparent relationship reflecting the low number of tows where the mean densities of razor clams were greater than 2 m^{-2}. Counts of razors which had partially emerged were assigned as *E. siliqua* or *E. magnus* based on the species ratio of fully emerged individuals. Since the number of fully emerged razor clams exceeded the partial emerged count by at least three times on every tow, this is not expected to have contributed any substantial error to the final density estimates of each species. The relationship between electrical stimulation exposure and emergence was studied further in a series of depletion experiments described later in this report.

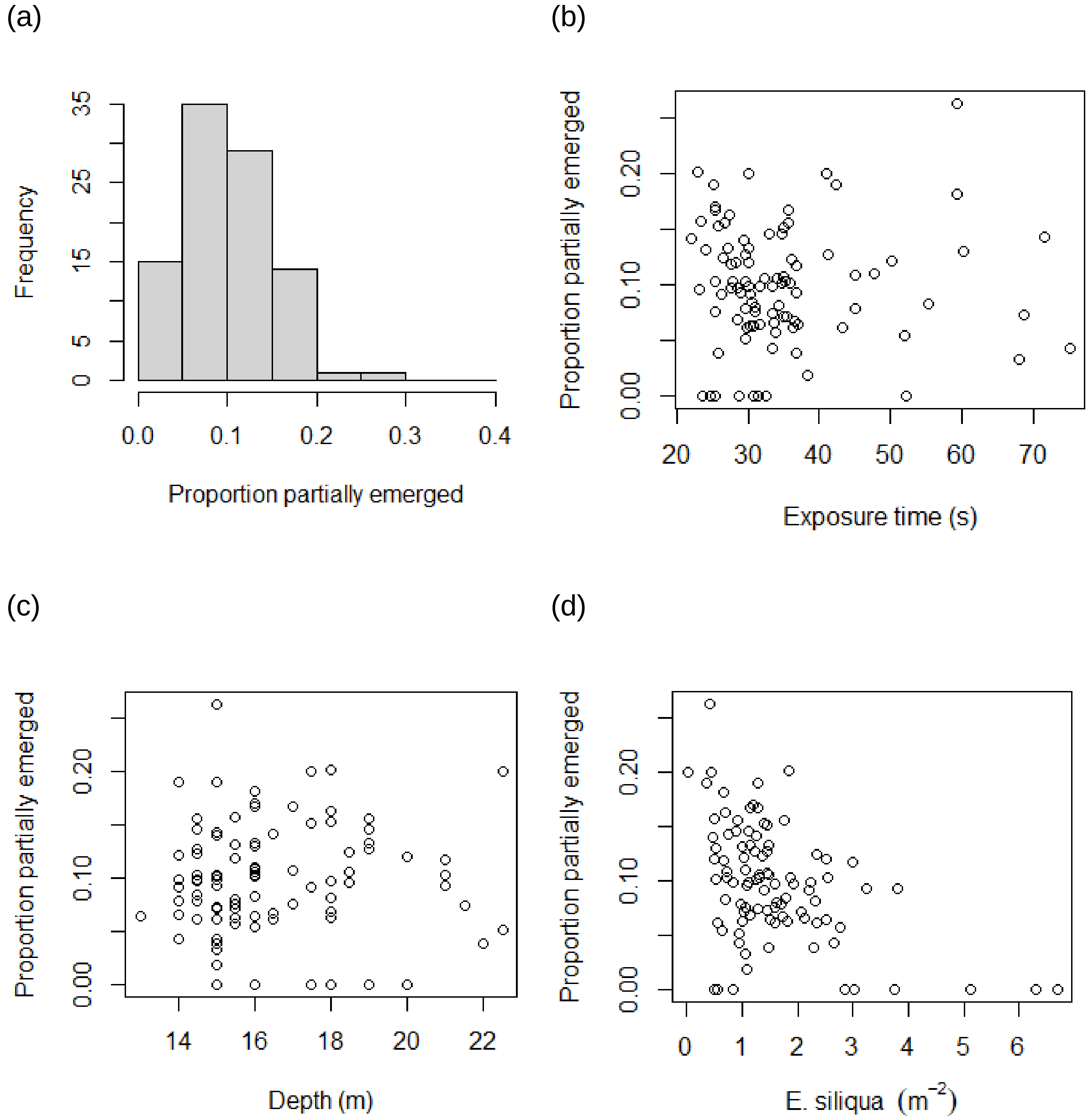
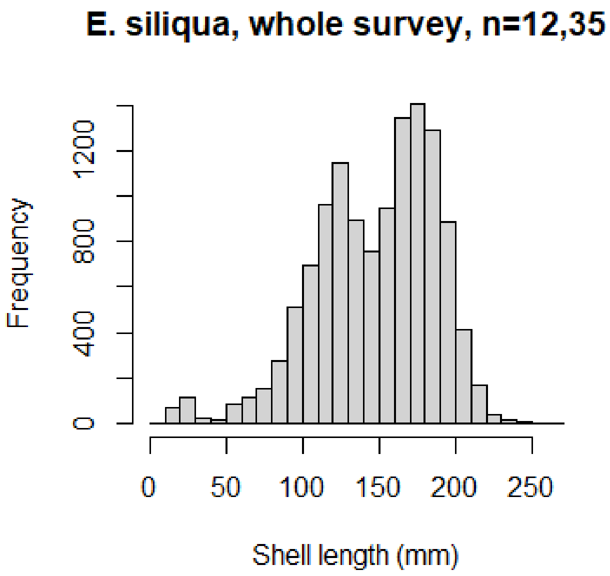


Figure 15: The proportion of the total razor clams which were partially emerged in each tow: (a) frequency distribution of partial emergence proportions and (b) plotted against the mean exposure time to the electrical field (c) plotted against the water depth at the time of the tow (d) plotted against the mean density of *E. siliqua* on the tow.

Razor clam size distributions

Pooling the *E. siliqua* length data (class 1 objects) from all the tows suggests there were two main size modes, one at around 120–130 mm and the other around 170–180 mm (Figure 16a). There were also a small number of clams of less than 50 mm shell length which were assumed to be *E. siliqua* because of the dominance of this species at the locations where these very small razors were recorded. The size distribution of *E. siliqua* on the fished sector (north of latitude 56ºN) was similar to the overall pattern, but the mode of the larger sizes was slightly smaller at 160–170 mm (Figure 16b). In comparison, the size distribution of *E. siliqua* in the unfished sector (south of latitude 56ºN) was dominated by larger clams with the mode at 170–180 mm. There were proportionally less medium-sized razors (100 to 150 mm shell length) and no very small razors (< 50 mm).

(a)



(b)

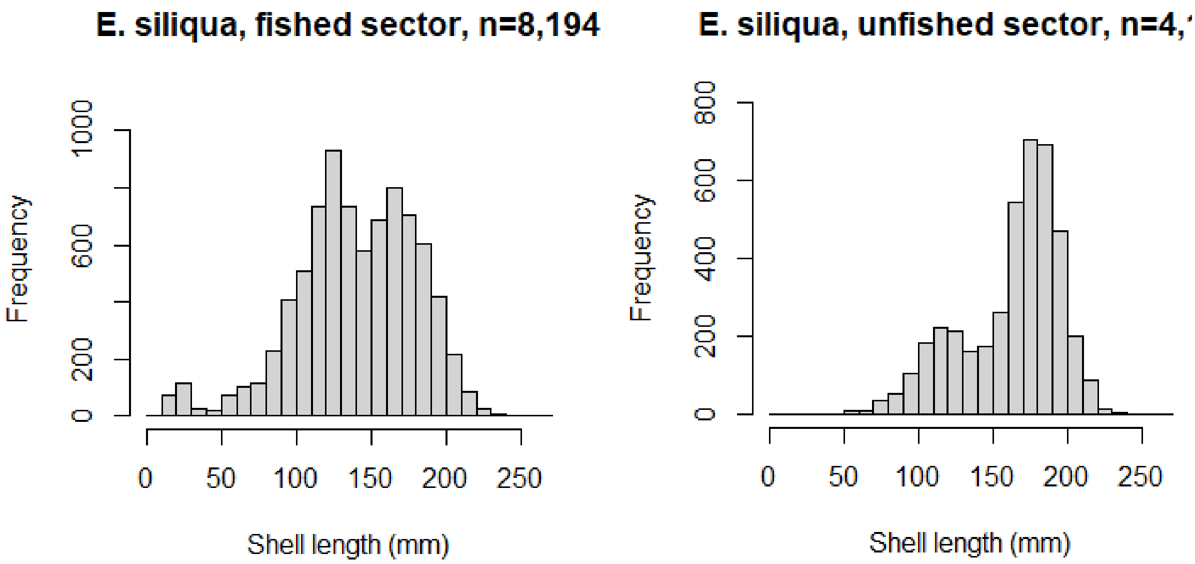


Figure 16: Frequency histograms for *E. siliqua* reconstructed lengths from the video tows. (a) all tows combined; (b) tows north of latitude 56°N; (c) tows south of latitude 56°N. n= total number of razor clams measured for shell length (mm).

The differences in the shell length distributions between the presently fished and unfished areas of Tarbert Bank can be better seen as empirical cumulative density plots which standardise for the different numbers of *Ensis* measured in the two areas (Figure 17). The two distributions are different at a high level of significance (Monte

Carlo two-sided Kolmogorov-Smirnov test, D = 0.307, p = 0.0005). This shows that there are a greater proportion of small and medium sized *Ensis* in the fished area and the dominance of larger razor clams in the presently unfished part of Tarbert Bank.

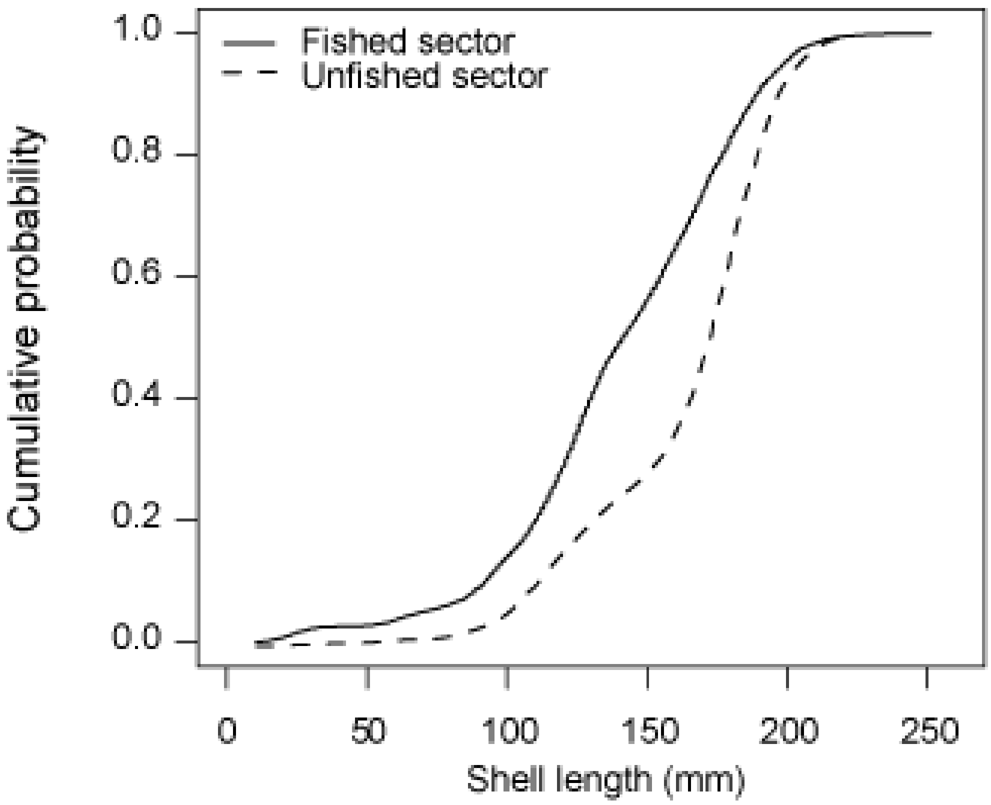


Figure 17: Empirical cumulative density plot for *E. siliqua* shell lengths comparing the presently fished (north of latitude 56ºN) and unfished (south of latitude 56ºN) areas of Tarbert Bank.

Ensis magnus are not normally collected by this fishery so the data are not plotted for this species. The mean shell length for *E. magnus* was 118 ± 2.5 mm (mean ± std dev) based on 570 observations.

Razor clam densities

Summary statistics for the razor clam densities are given in Table 1. The maximum density of *E. siliqua* of 6.68 m^{-2} was found in the northern fished sector. In the southern sector the maximum density was 2.99 m^{-2}. Mean densities were 1.57 ± 0.11 (mean ± SE) for the whole survey, and 1.87 ± 0.17 and 1.16 ± 0.11 m^{-2} for the northern and southern sectors respectively.

Table 1: Summary statistics for *E. siliqua* densities (nos m^{-2}) by shell length size group and survey area.

Shell size	Area	Tows	Zero counts	Min	Max	Median	Mean	SE	95% CI	Std Dev
Large	All	95	1	0.00	2.57	0.79	0.83	0.05	0.10	0.50
	North	55	0	0.06	1.88	0.82	0.82	0.05	0.10	0.37
	South	40	1	0.00	2.57	0.65	0.84	0.10	0.20	0.64
Medium	All	95	1	0.00	4.65	0.34	0.57	0.08	0.15	0.75
	North	55	0	0.11	4.65	0.52	0.80	0.12	0.24	0.90
	South	40	1	0.00	1.60	0.20	0.26	0.04	0.08	0.25
Small	All	95	5	0.00	2.39	0.06	0.17	0.03	0.07	0.34
	North	55	2	0.00	2.39	0.10	0.26	0.06	0.11	0.42
	South	40	3	0.00	0.67	0.04	0.06	0.02	0.03	0.10
All	All	95	0	0.02	6.68	1.30	1.57	0.11	0.23	1.12
	North	55	0	0.47	6.68	1.49	1.87	0.17	0.34	1.27
	South	40	0	0.02	2.99	1.06	1.16	0.11	0.22	0.70

However, the distributions of the densities tended to be right-skewed (Figure 18) so that the median densities were slightly lower at 1.30 m^{-2}, for the whole survey, and 1.49 and 1.06 m^{-2} for the northern and southern sectors respectively.

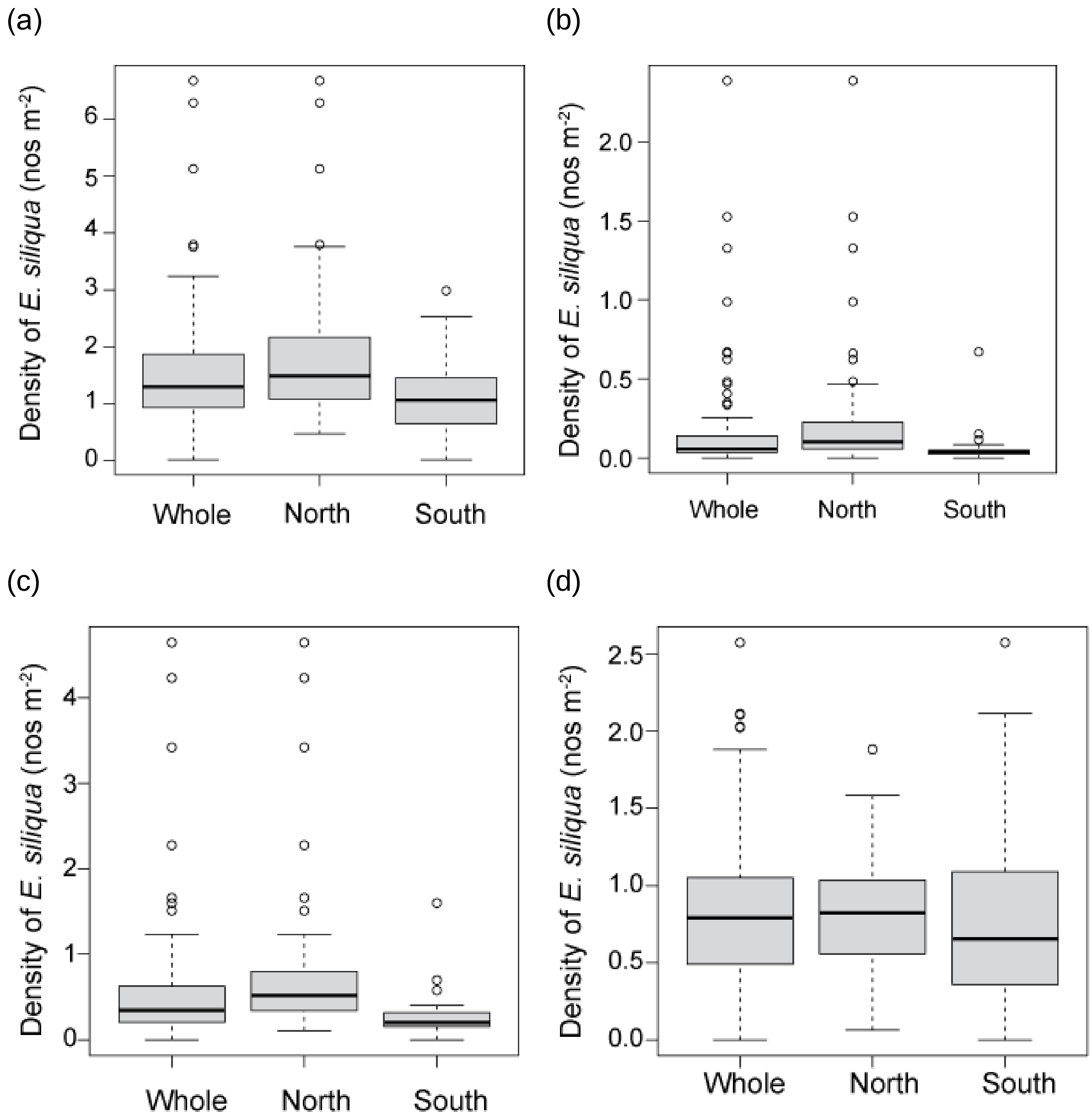


Figure 18: Boxplots of the densities of *E. siliqua* by surveyed area for (a) all shell sizes; (b) small sizes (< 100 mm shell length); (c) medium sizes (>=100 mm and < 150 mm shell length); (d) large sizes (>= 150 mm shell length). Heavy horizontal bars indicate the median sizes and boxes the interquartile ranges.

The spatial density distribution of *E. siliqua* is shown in Figures 19, 21 and 23. It should be noted that the tidal elevation on Tarbert Bank is approximately up to 3.5 m above chart datum on and 0.5 m above chart datum at low water on spring tides, so one needs to add approximately 1.5 m to the charted depths to derive the average water depth over a whole tidal cycle at a tow location. The actual water depths above chart datum will also be influenced by wind conditions and the topography of the bank.

The maximum density of large *E. siliqua* (≥ 150 mm shell length) was observed in the southern unfished sector at 2.57 m^{-2} (Table 1). Here the highest densities of large razors appeared to follow the curve of the bank between the 20-15 m depth contour (Figure 19). Densities were lower moving to the east but it is difficult to determine the westerly extent as tows deeper than 20 m were generally not possible with the electrical cables available. In the presently fished sector (north of 56ºN) larger sized *E. siliqua* were more broadly distributed with a maximum of 1.88 m^{-2} (Table1).

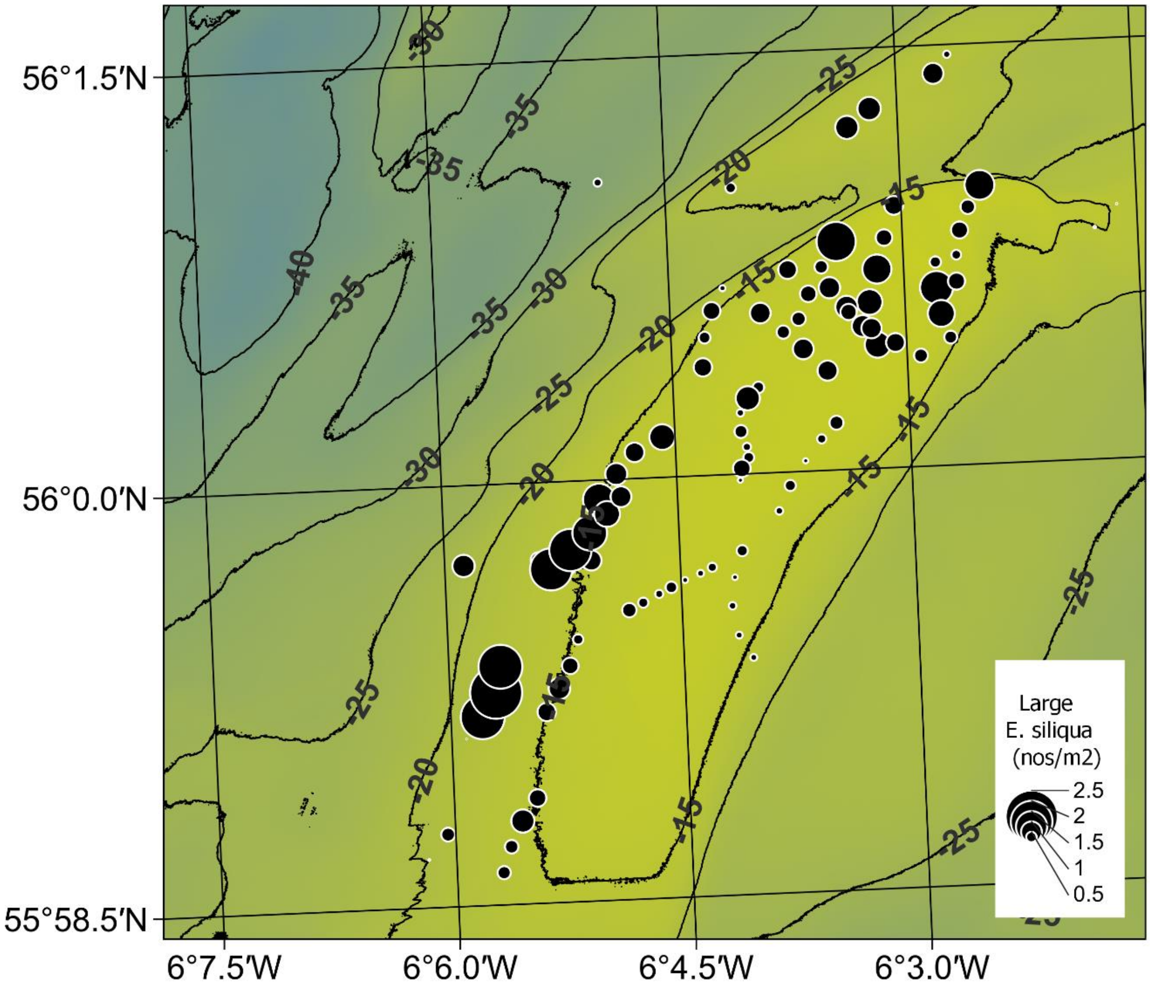


Figure 19: Spatial density distribution of large sized *E. siliqua* (> 150 mm shell length) overlaid on the bathymetry of Tarbert Bank. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-points of the video tows. The contour lines indicate the charted depths (m). Not to be used for navigation.

For the large *E. siliqua* there was no obvious relationship between density and water depth at the time of sampling when considering the whole survey (Figure 20a). However, when considering the northern fished sector on its own, there was a tendency for higher densities of large razor clams to be found at shallower depths (Figure 20b). For the southern unfished sector, the reverse trend was apparent (Figure 20c). However, it must be noted that these patterns are based on relatively low numbers of tows conducted at depths exceeding 18 m.

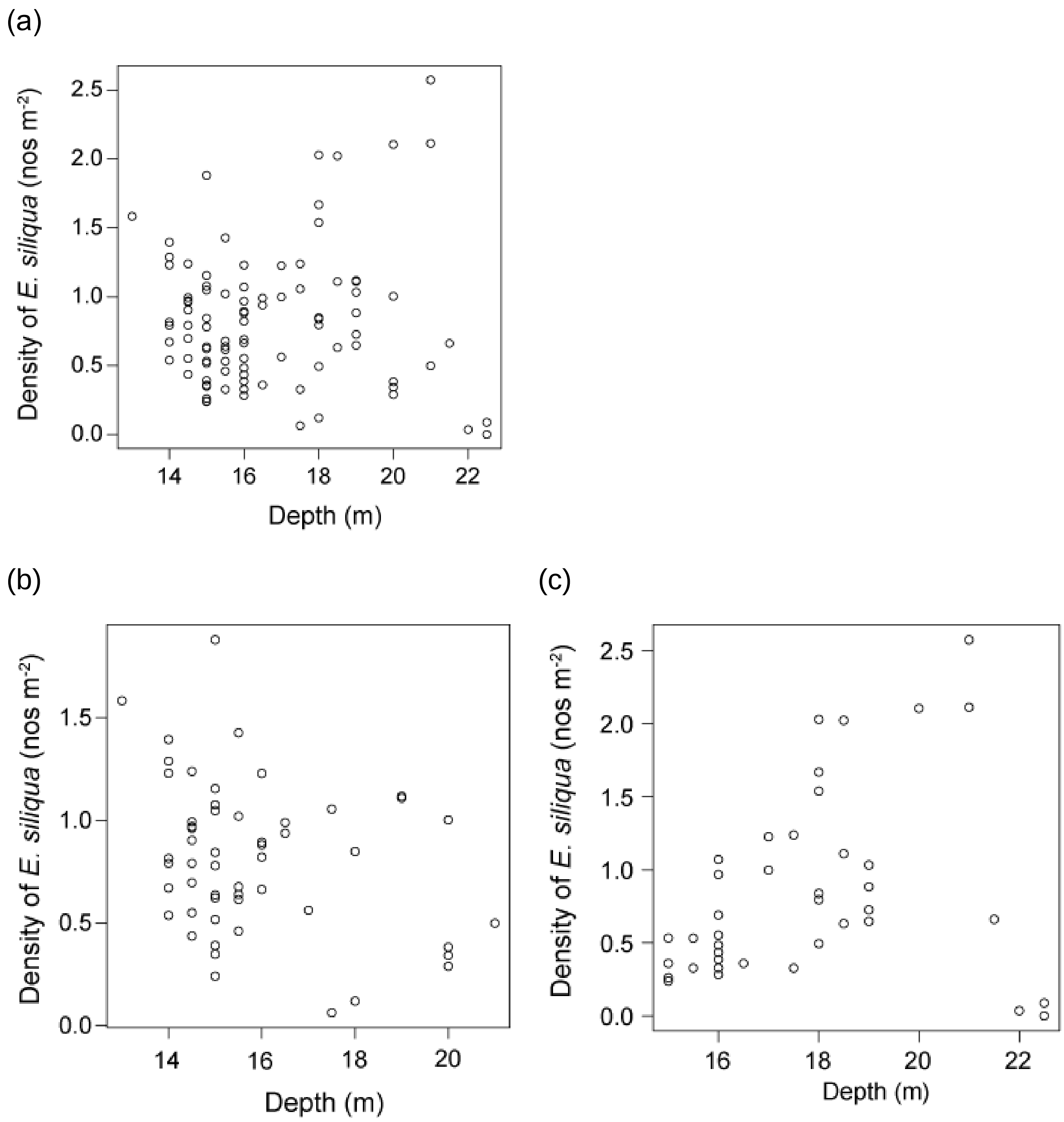


Figure 20: Relationships between the density of large size *E. siliqua* (≥ 150 mm shell length) and the water depths at the time of sampling: (a) Whole survey; (b) Northern presently fished sector; (c) Southern presently unfished sector. Note that water depths are not corrected to chart datum in this plot and tidal elevation can be up to approximately 3 m.

Higher densities of medium sized *E. siliqua* (≥ 100 mm and < 150 mm shell length) were found almost exclusively in the northern, presently fished sector where the densities were up to 4.65 m^{-2} (Table 1, Figure 21). In comparison, the maximum density of medium sized razors in the southern sector was 1.60 m^{-2}.

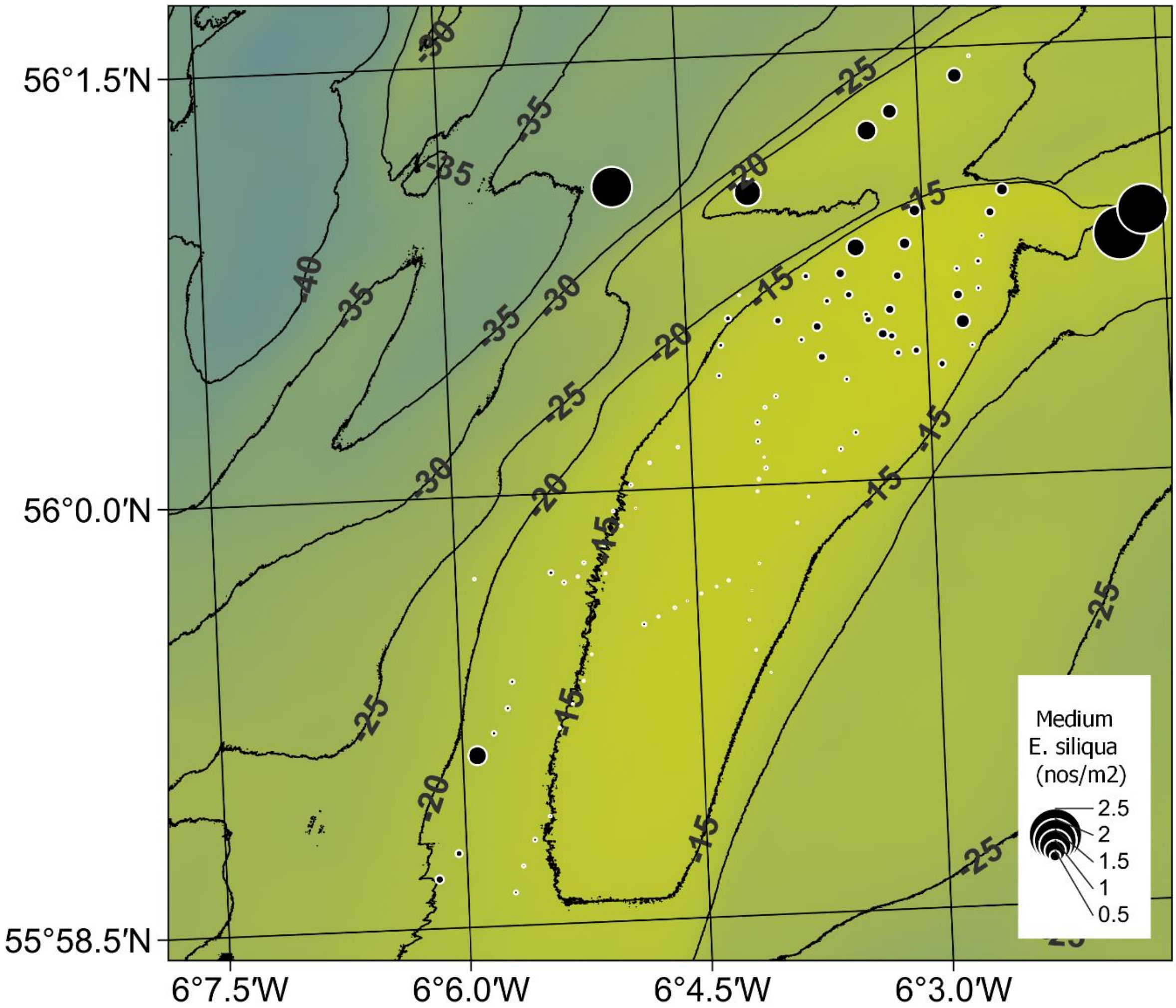


Figure 21: Spatial density distribution of medium sized *E. siliqua* (>100 and <= 150 mm shell length) overlaid on the bathymetry of Tarbert Bank. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-points of the video tows. The contour lines indicate the charted depths (m). Not to be used for navigation.

Considering the whole survey or the presently fished (northern) sector, there was a tendency for higher densities of medium sized *E. siliqua* to be found on deeper tows, however low densities also occurred at depths exceeding 18 m (Figure 22 a and b). For the southern unfished sector, the densities of medium-sized razors were low, although slightly elevated on deeper tows (Figure 22c). It must be noted that these patterns are based on relatively low numbers of tows conducted at depths exceeding 18 m.

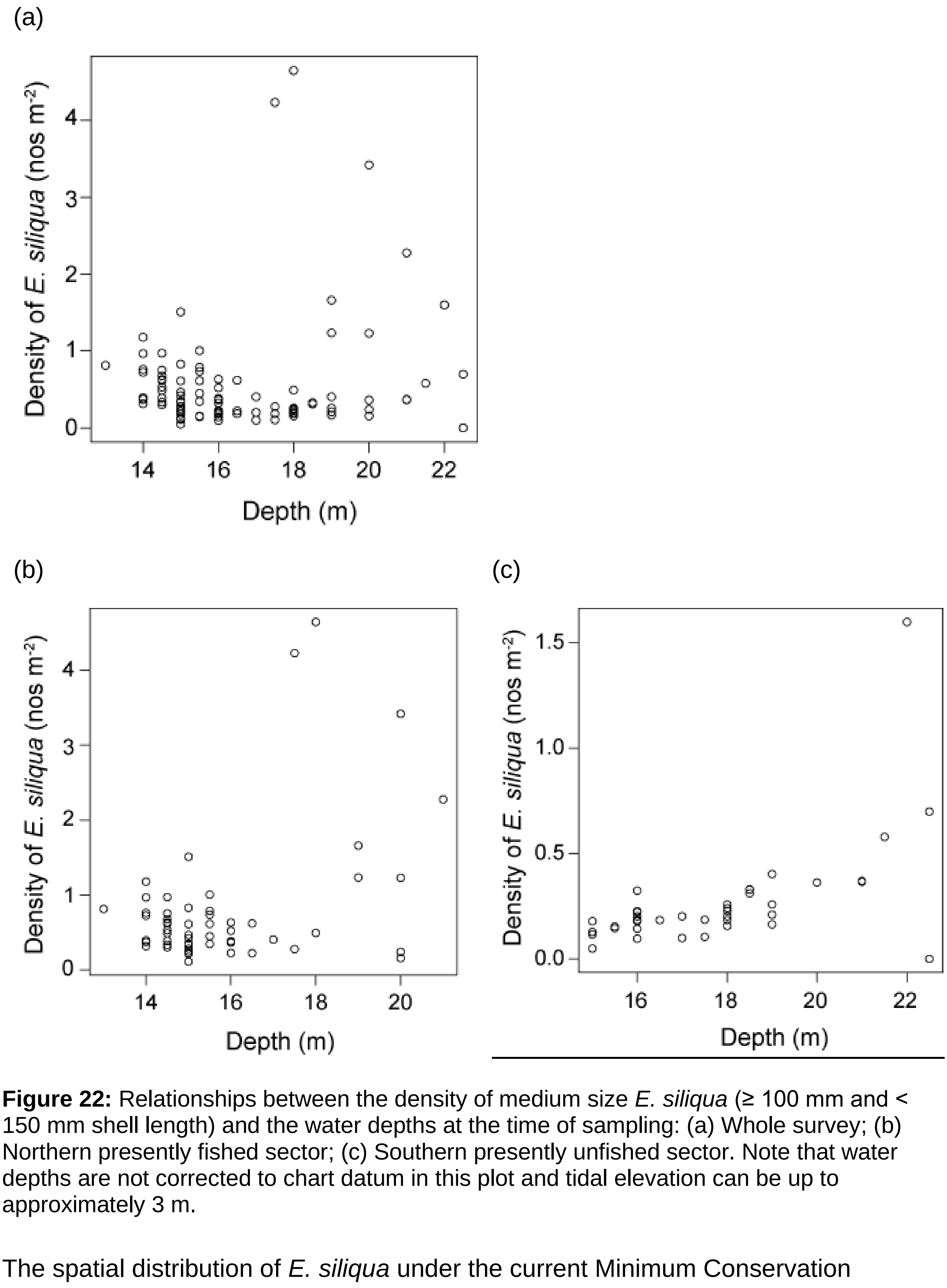


Figure 22: Relationships between the density of medium size *E. siliqua* (≥ 100 mm and < 150 mm shell length) and the water depths at the time of sampling: (a) Whole survey; (b) Northern presently fished sector; (c) Southern presently unfished sector. Note that water depths are not corrected to chart datum in this plot and tidal elevation can be up to approximately 3 m.

The spatial distribution of *E. siliqua* under the current Minimum Conservation Reference Size of 100 mm shell length appeared similar to that of the medium sized razor clams (comparing Figure 23 with Figure 21), but with a slightly lower maximum density of 2.39 m^{-2} (Table 1). Small size razors in the southern unfished sector were

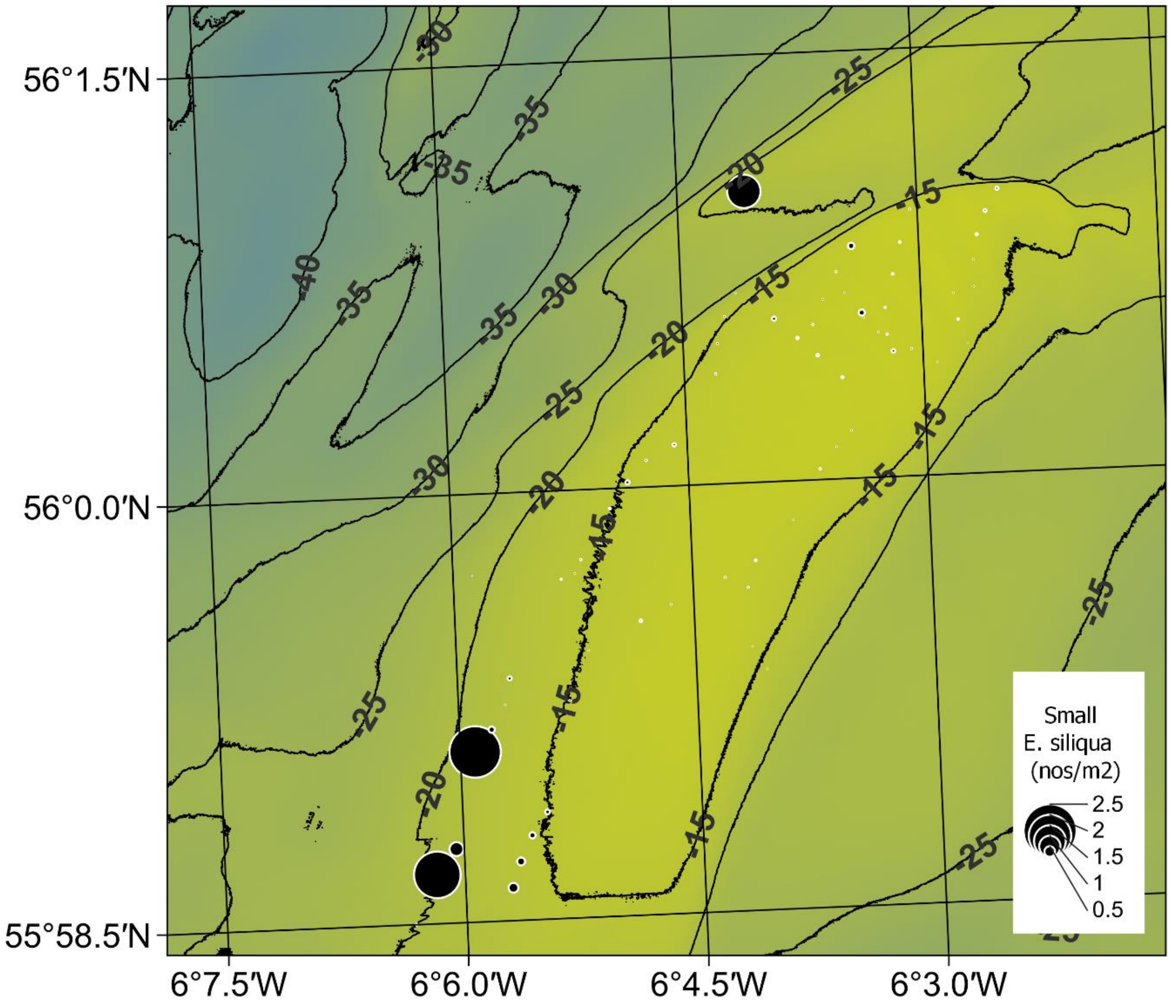


Figure 23: Spatial density distribution of small sized *E. siliqua* (<= 100 mm shell length) overlaid on the bathymetry of Tarbert Bank. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-points of the video tows. The contour lines indicate the charted depths (m). Not to be used for navigation.

largely confined to a patch off south-western edge of the bank with a maximum density of 0.67m^{-2}. The spatial distributions of both the smaller and medium-sized razor clams (comparing Figure 23 with Figure 21) could be linked with water circulation patterns around the bank which could be an important factor in the recruitment dynamics.

The depth distribution of the small *E. siliqua* is of interest because of suggestions in the literature that razor clams recruit from stocks of juveniles found either in very shallow or deeper water around the periphery of the main beds (Fahy & Gaffney 2001). If correct, deeper areas would be less accessible to the fishery due to the limitation on dive times when using compressed air SCUBA equipment and may provide a *de facto* protected source for new recruits. For Tarbert Bank there was some evidence that the highest densities of smaller *E. siliqua* tended to be associated with deeper tows (Figure 24). However, this conclusion is based on a relatively small number of tows conducted deeper than 18 m. It should also be noted that some of the deeper tows had low densities of small *Ensis*.

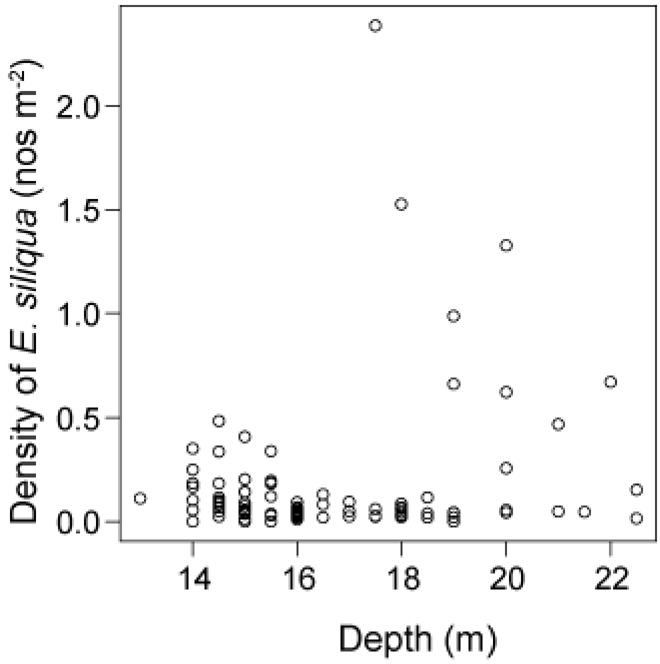


Figure 24: Relationship between the density of small size *E. siliqua* (below the Minimum Conservation Reference Size of 100 mm shell length) and the water depth at times of sampling. Separate plots for north and south of 56ºN are not shown because of the low number of small size *E. siliqua* found in the southern sector. Note that water depths are not corrected to chart datum in this plot and tidal elevation can be up to approximately 3 m.

Apart from a single tow off the north-western edge of the bank, *E. magnus* only occurred in higher densities in the deeper water off the south-western tip of the bank (Figure 25). The maximum density was 1.16 m^{-2} (mean ± std dev 0.065 ± 0.18 m^{-2}) and was coincident with coarser sediment. The tendency for this species to be found in slightly coarser sediments compared to those favoured by *E. siliqua* is well known (Fahy et al. 2001).

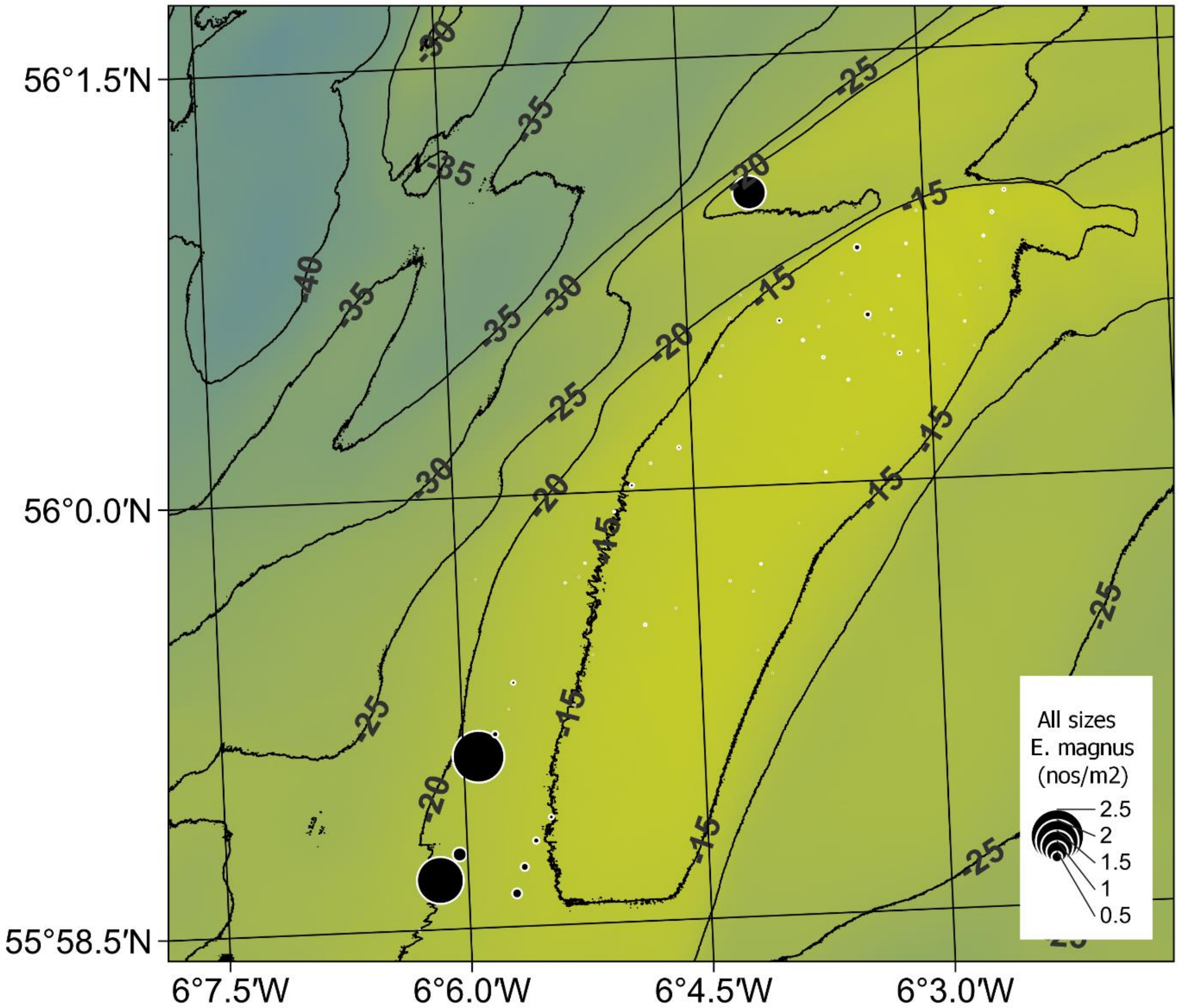


Figure 25: Spatial density distribution of *E. magnus* (all sizes) overlaid on the bathymetry of Tarbert Bank. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-points of the video tows. The contour lines indicate the charted depths (m). Not to be used for navigation.

Incidental observations

The total numbers of incidental organisms recorded on the videos are summarised in Table 2 and examples of the commoner organisms shown in Figure 26. Sandeels (Ammodytidae) were the most common incidental organism observed on the videos. Most were observed to be stunned by the electric field although some were actively swimming. The next most common incidental organism overall was the common starfish (*Asterias rubens*). Brittlestars were also abundant and were probably *Ophiura ophiura* although the features visible on the videos were not detailed enough to confirm this identification. Crabs (probably *Carcinus maenas*) and hermit crabs (unidentifiable to species) were also present. Relatively low numbers of juvenile flatfish were observed (these being most likely dab *Limanda limanda* or plaice *Pleuronectes platessa*) but the timing of the surveys was rather early in the year for large numbers of 0-group juvenile flatfish to be present (Gibson et al. 1993).

Table 2: Total counts of other organisms observed on the video recordings by survey date.

Taxa	16/02	25/02	26/02	27/02	28/02	01/03	02/03	03/03	Total
Sandeel	521	601	1456	742	609	731	2,038	74	6,772
Starfish	6	46	14	44	43	28	32	91	304
Brittlestar	12	10	9	39	41		83		194
Crab	3	12	10	22	3	50	13	46	159
Hermit crab	5	2	6	17	18	10	19	5	82
Flatfish	3		1	6	5	4	3	1	23
Heart urchin				2				1	3
Gurnard?						1		2	3
Scallop	1					1			2
Surf clam	1			1					2
Sand dollar						1			1

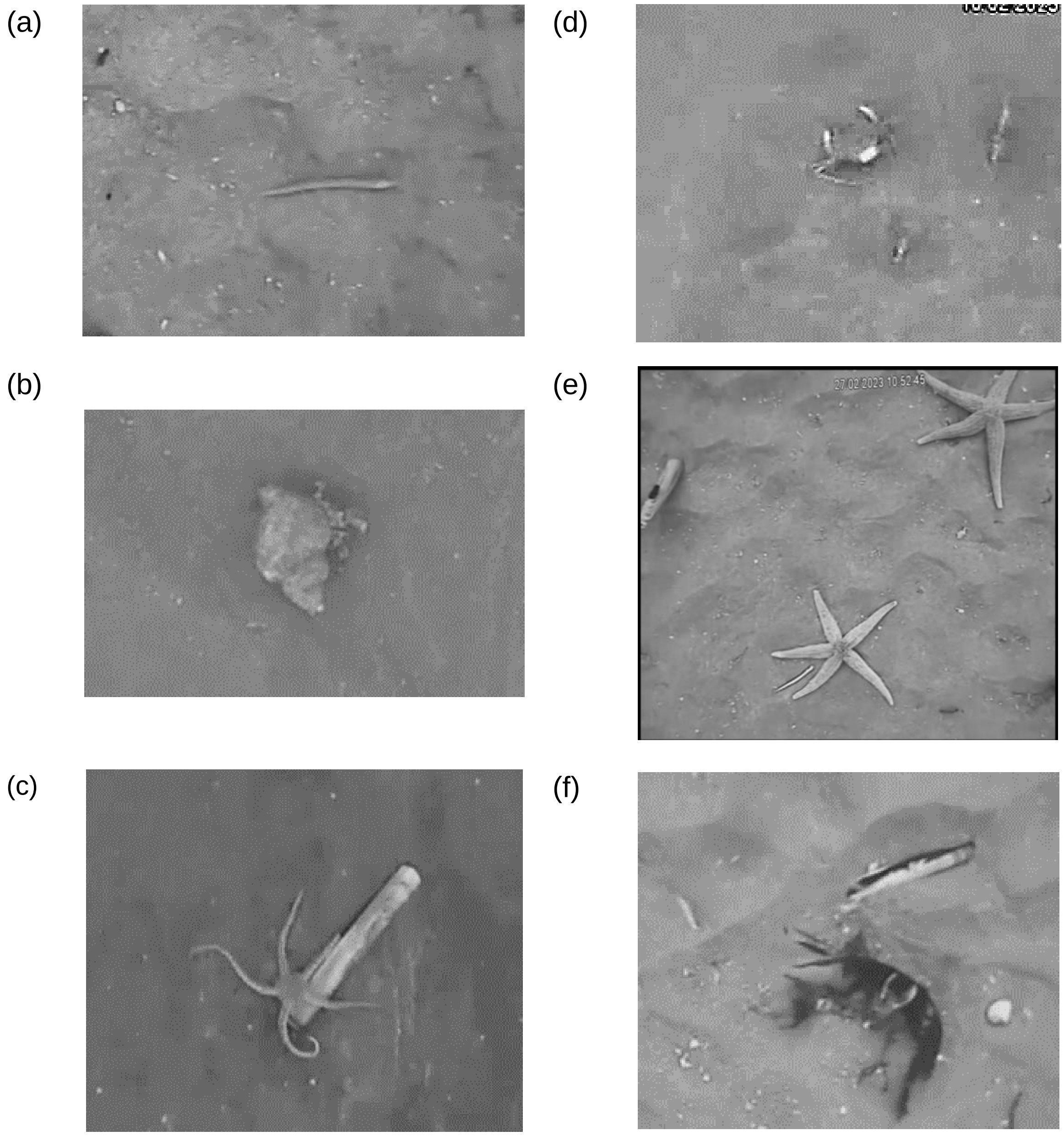


Figure 26: Examples of incidental observations on the video recordings: (a) stunned sandeel; (b) active hermit crab; (c) brittlestar on emerged Ensis siliqua; (d) crab; (e) starfish; (f) kelp fragment. Note the images are not shown to a common scale.

Efficiency of electrofishing

Although the efficiency of the electrofishing technique has been assumed to be high (Fox et al. 2019) this was based on limited tank-based data (Murray et al. 2014) and has never been scientifically investigated under field conditions. Furthermore, anecdotal evidence from fishers suggests the emergence speed of razor clams is affected by water temperature, being slower in winter and early spring when the water temperature is colder. It has also been suggested that the depths to which the clams burrow may be affected by other factors such as air pressure and that this can also affect their emergence speeds. Clearly, slow responses could impact survey accuracy using the towed video sled if clams continue to emerge after the towed cameras have passed over an area of seabed.

On the last working day on Tarbert Bank (4th March 2023) a series of depletion experiments were conducted. This was facilitated by neap tides on that date which allowed the electrical gear to be placed stationary on the same ground for around ten minutes. Experiments were conducted in 13.4 to 13.8 m water depth. The electrical stimulation was turned on for 30 s after which a diver collected all the emerged clams within the spread of the electrodes (6 m^2) and placed them in a sample bag. This process was repeated twice more. The sample bags were then lifted on board and the razor clams counted and measured. All the razor clams were returned to the sea after being measured. The vessel and electrofishing and video gear were then warped forwards to a fresh area of ground. In total the experiment was repeated 18 times.

Ten of the 18 replicates reached zero further emergences after the second or third 30 s stimulation (Table 3). For three of the replicates the proportion which emerged following the first stimulation was as low as 0.5 but for the remaining 15 replicates was above 0.75. On average, the proportion of the total clams which had emerged after the first 30 s electrical stimulation was 0.82, following the second stimulation was 0.12 and following the third stimulation was 0.06 (Table 3). The results are slightly skewed so that median emergence proportions were 0.87, 0.09 and 0.00 after 30-, 60- and 90-seconds electrical stimulation (Figure 27).

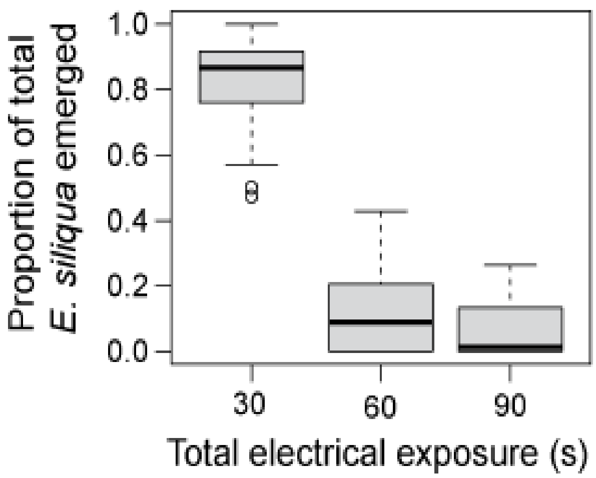


Figure 27: Boxplots of results of the depletion experiment. Solid black horizontal lines indicate the median, boxes indicate the inter-quartile range.

Table 3: Details of depletion study by replicate experiment.

Replicate	Lat (deg N)	Lon (deg W)	Counts of emerged *E. siliqua* after total exposure to electrical field				Proportion of total emerged after each exposure		
			30s	60s	90s	Total	30s	60s	90s
1	56.00465	6.06033	9	5	5	19	0.47	0.26	0.26
17	56.00604	6.06033	8	5	3	16	0.50	0.31	0.19
5	56.00517	6.06019	8	6	0	14	0.57	0.43	0.00
15	56.00592	6.06031	14	2	5	21	0.67	0.10	0.24
8	56.00548	6.06035	19	6	0	25	0.76	0.24	0.00
9	56.00557	6.06038	23	6	0	29	0.79	0.21	0.00
10	56.00567	6.06041	33	6	1	40	0.83	0.15	0.03
6	56.00528	6.06026	11	0	2	13	0.85	0.00	0.15
13	56.00580	6.06038	13	1	1	15	0.87	0.07	0.07
4	56.00505	6.06019	13	0	2	15	0.87	0.00	0.13
16	56.00599	6.06034	13	2	0	15	0.87	0.13	0.00
11	56.00569	6.06038	28	3	1	32	0.88	0.09	0.03
18	56.00612	6.06034	11	1	0	12	0.92	0.08	0.00
12	56.00573	6.06033	26	2	0	28	0.93	0.07	0.00
2	56.00481	6.06017	16	0	0	16	1.00	0.00	0.00
3	56.00491	6.06021	9	0	0	9	1.00	0.00	0.00
7	56.00539	6.06032	5	0	0	5	1.00	0.00	0.00
14	56.00584	6.06035	9	0	0	9	1.00	0.00	0.00
mean							0.82	0.12	0.06
SE							0.04	0.03	0.02
median							0.87	0.09	0.00

With increasing electrical stimulation, the median length of emerging razors increased from 165 to 180 mm (Figure 28) but the differences were not statistically significant (Kruskall-Wallis chi-squared = 1.82, df = 2, p = 0.40). It should also be noted that because the numbers of *E. siliqua* emerging declined strongly with each exposure the sample sizes are not equal (268 after Exposure 1, 43 after Exposure 2 and 22 after Exposure 3).

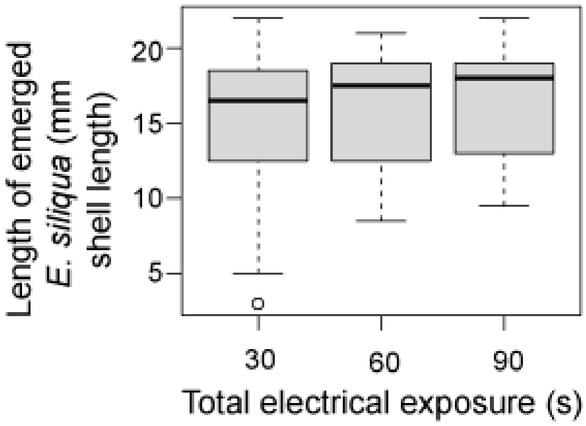


Figure 28: Boxplots of shell lengths of emerged E. siliqua during the depletion experiment. Solid black horizontal lines indicate the median, boxes indicate the inter-quartile range.

Based on the estimated exposure times during the Tarbert Bank survey tows (Figure 11d), average catchability should be at least 82%, and given that many of the tows had longer exposure times, overall survey efficiency is likely to exceed this value.

In future surveys the gear could be towed at a slightly slower speed since increasing the exposure time to 60 seconds should ensure a catchability close to 100%, even under colder water conditions. This would increase the time required to complete tows of sufficient length so the trade-off between further improving catchability versus increased survey cost, or a reduction in the number of tows would require careful consideration.

Discussion

There are only a limited number of historical estimates of razor clam densities around Scotland with which to compare the present findings. McKay (1992) used a suction dredge to survey a variety of shellfish but with very limited exploration of the waters around Jura and Colonsay. Local density estimates for *Ensis* (both species combined) made by divers in Loch Nevis, Scotland were reported to be up to 17 clams m^{-2}. More recently several razor clam surveys using the combined electrofishing towed-video approach have been conducted by Fox et al. (2017, 2018, 2021). From these, the maximum densities of *E. siliqua* recorded to the north of Barra were around 3 m^{-2} whilst along the Ayrshire coast only a few tows reached as high as 1 m^{-2}. In contrast, the maximum density found in Largo Bay (Firth of Forth) was 11 m^{-2} and the average density across all the tows was 4 m^{-2}. The densities of *E. siliqua* on Tarbert Bank were up to 6.68 m^{-2} with an average density of 1.57 ± 0.11 m^{-2} (mean ± SE). The northern part of the bank has been fished throughout the Scottish Government trial whereas the southern sector has not been fished for around 5 years. This recent history seems to be reflected in the razor clam density and length distributions where the maximum and average densities, the relative proportion of larger razors in the population and the modal size of the large-size group (> 150 mm shell length) were higher in the southern sector. However, both the maximum and average density of the medium size-group (≥ 100 and < 150 mm shell length) and small size-group (<100 mm shell length) were lower in the unfished area.

Particularly noticeable was the spatial distribution of the small razors which were found at higher densities around the periphery of the northern fished part of the bank. It is tempting to speculate that reduction in the densities of the largest razors in this area may have promoted recruitment of younger razors by reducing competition for food or space. However, this pattern could also be a result of the water circulation patterns around Tarbert Bank. Very little is known regarding recruitment dynamics of *Ensis* spp. although it has been hypothesized that young razors may settle around the edges of established beds and migrate into the main beds as they grow (Fahy & Gaffney 2001). It would be worth investigating further out from Tarbert Bank, particularly to the west in the unfished sector to see if small razors are also present in that area, but this will require longer electrical cables than were available for the current survey.

Tow speeds in the present surveys ranged from 1.6 – 5.4 m min^{-1} which are similar to those when other vessels have been employed to conduct razor clam surveys (Fox 2018, Fox 2021). It has been suggested that the proportion of razors which are partially emerged might provide an index for how efficiently the electrofishing gear is working (Fox 2018). For studies along the Ayrshire coast, this proportion averaged 0.25 but was as high as 0.60 on some stations in Culzean Bay. However, in Largo Bay (Firth of Forth) the proportion of partially emerged *Ensis* was 0.15 or less (Fox 2021). On Tarbert Bank the median proportion of partial emergence was 0.098 with only a few tows exceeding 0.20 suggesting that the gear was fishing efficiently. Furthermore, there did not appear to be any clear relationship between the proportion of razor clams which were partially emerged and water depth at the time of sampling, or with the estimated length of exposure to the electrical field. The catch efficiency of the electrofishing method was studied further in a series of depletion experiments on Tarbert Bank.

One area of uncertainty in past surveys has been the efficiency of the electrofishing gear. The depletion experiment conducted on Tarbert Bank is the first time this has been scientifically investigated under field conditions. The results suggest that on average the electrofishing gear was 82% efficient based on a single 30 s exposure to the electrical field. The other survey technique where efficiency has been measured is hydraulic dredging which was estimated to have 100% catchability across a width of 0.45 m dropping to 42% across a width of 1.01 m, which represented the extent of disturbed ground (Hauton et al., 2007). These efficiencies contrast to non-hydraulic dredges used for scallops and oysters where efficiency is in the region of 10 –35% (Marine Institute and Bord Iascaigh Mhara, 2021). Hydraulic dredging was used in the surveys conducted by MacKay (1992) and is used for scientific stock assessments in Ireland (Fahy and Carroll, 2007, Marine Institute and Bord Iascaigh Mhara, 2021). Hydraulic dredging creates more physical disturbance compared to electrofishing although Tuck et al. (2000) concluded that the infaunal communities present in sandy sediments were well adapted to physical disturbance and would recover after a few weeks. However, mortality rates of organisms discarded during hydraulic dredging may be significant given recorded levels of damage to the shells of bivalves, including *Ensis* spp. (Marine Institute and Bord Iascaigh Mhara, 2021). In contrast, non-target organisms are not collected during electrofishing and available scientific evidence suggests high rates of recovery shortly after the electrodes have passed (Murray et al., 2014). In conclusion, electrofishing combined with towed video appears to be an effective survey tool for *Ensis* whilst also causing minimal collateral damage. Anecdotal evidence also suggests that the rates of razor clam emergence when electrofishing may be even faster under warmer conditions, so it is recommended that the depletion experiments be rerun during summer months to test this hypothesis.

Murray et al. (2014) mentioned that stunned razor clams might be predated on the seabed before they have a chance to rebury. When commercial divers leave undersized clams on the seabed predation could impact the sustainability of the stock if sufficiently high. However, the numbers of benthic predators seen on the videos from Tarbert Bank appeared rather low. On several occasions, brittlestars were seen apparently feeding on stunned razors but it could not be ascertained whether this leads to irrecoverable damage to the clams. In contrast, eider ducks, which may be important predators on razor clams in Largo Bay (Fox 2021), were not present during the survey. Large numbers of small sandeels were seen on the videos. However, Murray et al. (2014) suggested that sandeels recover in a few minutes following exposure to the electrical field, although this conclusion was based on relatively limited testing.

The data collected in this survey provides a baseline with which to compare *Ensis* densities and sizes from future surveys on Tarbert Bank. Comparison between the presently fished and unfished portions of the bank suggests that the fishery has resulted in a detectable reduction in the proportion of larger razors north of latitude 56°N. However, there may also be differences in growth conditions between the two areas because both the maximum and average densities of *E. siliqua* seemed to be lower in the unfished area. The finding that higher densities of small and medium size *E. siliqua* were mainly confined to the northern part of the bank suggests that either local hydrography plays an important role in recruitment dynamics, or that settlement of small razors has been encouraged by a reduction in the densities of larger, older razor clams in the fished area.

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Appendix 1: Summary details of tows on Tarbert Bank.

Date	Tow	Depth (m)	UTC Start (h:min)	Lat Mid-tow (deg)	Lon Mid-tow (deg)	Tow Duration (mins)	Tow Length (m)	Av Speed (m min^{-1})	Average Exposure Time (s)	Swath Width (m)	Swept Area (m^2)	Count Whole siliqua Small (Cat 1)	Count Whole siliqua Medium (Cat 1)	Count Whole siliqua Large (Cat 1)	Count Whole siliqua All Sizes (cat 1)	Count Partial siliqua (Cat2)	Count Tops (Cat3)	Count Whole magnus (Cat4)	Count Partial magnus (Cat5)	Mean Dens siliqua Small (m^{-2})	Mean Dens siliqua Medium (m^{-2})	Mean Dens siliqua Large (m^{-2})	Mean Dens siliqua All Sizes (m^{-2})
16/02	1	14.5	09:28	56.00511	-6.06592	14	48	3.5	35	1.0	50.5	2	12	22	36	5	7	0	0	0.050	0.300	0.551	0.901
16/02	2	15.0	09:52	56.00449	-6.06710	15	26	1.7	69	1.0	27.4	1	6	28	35	3	3	0	0	0.041	0.247	1.155	1.443
16/02	3	15.0	10:21	56.00364	-6.06795	14	23	1.7	72	1.0	24.5	1	6	6	13	5	3	0	0	0.058	0.349	0.349	0.756
16/02	4	15.0	10:49	56.00253	-6.06797	14	44	3.1	38	1.0	45.9	6	14	26	46	7	1	0	0	0.144	0.335	0.622	1.101
16/02	5	15.0	11:14	56.00160	-6.06741	12	46	3.8	31	1.0	47.8	2	5	18	25	2	0	0	0	0.043	0.109	0.391	0.544
16/02	6	15.0	11:37	56.00097	-6.06726	14	22	1.6	75	1.0	23.4	3	6	11	20	2	1	0	0	0.141	0.282	0.518	0.941
16/02	7	15.0	12:00	56.00034	-6.06805	14	25	1.8	68	1.0	25.8	0	5	19	24	5	1	0	0	0.000	0.222	0.844	1.066
16/02	8	15.0	12:22	55.99964	-6.06825	15	30	2.0	59	1.5	45.5	0	6	8	14	0	5	0	0	0.000	0.179	0.238	0.417
16/02	9	16.0	13:20	55.99454	-6.07162	15	30	2.0	59	1.5	45.5	1	7	15	23	3	6	1	0	0.029	0.202	0.434	0.665
16/02	10	16.0	13:41	55.99421	-6.07289	15	34	2.3	52	1.5	51.7	2	7	16	25	3	0	0	0	0.041	0.143	0.328	0.512
16/02	11	16.0	14:02	55.99385	-6.07456	15	30	2.0	60	1.5	44.8	2	7	11	20	0	3	0	0	0.051	0.180	0.282	0.513
16/02	12	16.0	14:25	55.99345	-6.07605	15	33	2.2	55	1.5	48.8	2	4	23	29	4	3	0	0	0.048	0.096	0.552	0.696
16/02	13	16.0	14:46	55.99309	-6.07737	15	35	2.3	52	1.5	51.9	1	10	17	28	6	2	1	0	0.023	0.227	0.385	0.635
16/02	14	16.0	15:07	55.99261	-6.07910	15	40	2.7	45	1.5	60.0	3	9	24	36	5	5	0	0	0.060	0.181	0.483	0.725
16/02	15	16.0	15:28	55.99220	-6.08061	15	38	2.5	48	1.5	56.6	2	16	34	52	2	7	3	0	0.041	0.324	0.689	1.054
25/02	16	14.0	09:47	56.00990	-6.05375	20	76	3.8	32	1.5	113.8	24	73	118	215	27	27	3	0	0.250	0.761	1.230	2.241
25/02	17	14.0	10:20	56.01184	-6.05282	13	59	4.6	26	1.5	89.0	8	56	108	172	14	19	3	0	0.103	0.723	1.394	2.221
25/02	18	14.0	10:48	56.01369	-6.05193	19	68	3.6	34	1.5	101.5	32	88	72	192	15	15	4	0	0.352	0.967	0.791	2.110
25/02	19	14.5	11:16	56.01558	-6.05075	22	88	4.0	30	1.5	132.4	58	116	108	282	21	20	3	0	0.485	0.970	0.903	2.359

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Date	Tow	Depth (m)	UTC Start (h:min)	Lat Mid-tow (deg)	Lon Mid-tow (deg)	Tow Duration (mins)	Tow Length (m)	Av Speed (m min^{-1})	Average Exposure Time (s)	Swath Width (m)	Swept Area (m^2)	Count Whole siliqua Small (Cat 1)	Count Whole siliqua Medium (Cat 1)	Count Whole siliqua Large (Cat 1)	Count Whole siliqua All Sizes (cat 1)	Count Partial siliqua (Cat2)	Count Tops (Cat3)	Count Whole magnus (Cat4)	Count Partial magnus (Cat5)	Mean Dens siliqua Small (m^{-2})	Mean Dens siliqua Medium (m^{-2})	Mean Dens siliqua Large (m^{-2})	Mean Dens siliqua All Sizes (m^{-2})
25/02	20	16.0	12:26	56.00644	-6.07172	18	85	4.7	25	1.5	127.9	3	39	90	132	10	29	3	0	0.029	0.382	0.882	1.293
25/02	21	17.0	12:51	56.00820	-6.07141	15	71	4.7	25	1.5	106.3	9	38	53	100	8	9	2	0	0.096	0.403	0.563	1.061
25/02	22	18.0	13:14	56.00977	-6.07055	17	79	4.6	26	1.5	117.9	6	48	83	137	5	26	2	0	0.061	0.491	0.849	1.401
25/02	23	20.0	13:39	56.01109	-6.06929	17	72	4.2	28	1.5	108.3	5	14	26	45	5	7	1	0	0.056	0.156	0.290	0.502
25/02	24	19.0	14:40	55.99542	-6.09004	17	62	3.6	33	1.5	93.0	0	30	54	84	10	16	0	0	0.000	0.403	0.726	1.129
25/02	25	17.0	15:06	55.99513	-6.08728	18	62	3.4	35	1.5	92.5	2	16	97	115	9	15	1	0	0.025	0.202	1.225	1.452
25/02	26	16.0	15:32	55.99525	-6.08441	15	71	4.7	25	1.5	106.5	4	16	84	104	3	22	0	0	0.046	0.184	0.967	1.197
25/02	27	16.0	15:56	55.99524	-6.09799	20	74	3.7	32	1.5	111.2	1	21	101	123	12	16	1	0	0.011	0.222	1.069	1.302
26/02	28	19.0	09:24	55.98636	-6.08982	18	79	4.4	27	1.5	119.0	4	20	84	108	16	19	0	0	0.042	0.210	0.883	1.135
26/02	29	19.0	09:50	55.98772	-6.08837	18	73	4.0	30	1.5	109.0	4	15	94	113	9	18	2	0	0.044	0.165	1.032	1.240
26/02	30	18.0	10:16	55.98904	-6.08712	18	70	3.9	31	1.5	104.9	2	17	73	92	12	7	0	0	0.022	0.185	0.794	1.001
26/02	31	18.0	10:43	55.99059	-6.08617	17	74	4.4	27	1.5	111.4	3	14	44	61	5	13	1	0	0.034	0.157	0.494	0.685
26/02	32	16.5	11:48	55.99772	-6.06426	22	73	3.3	36	1.5	108.9	2	18	35	55	5	4	1	0	0.021	0.185	0.359	0.564
26/02	33	15.5	12:21	55.99920	-6.06298	18	78	4.4	28	1.5	117.5	0	14	51	65	9	10	0	0	0.000	0.146	0.531	0.677
26/02	34	15.0	12:51	56.00063	-6.06124	17	69	4.1	29	1.5	103.9	1	17	19	37	9	8	3	0	0.013	0.216	0.242	0.470
26/02	35	14.5	13:17	56.00189	-6.05944	19	68	3.6	33	1.5	102.3	6	29	38	73	8	9	1	0	0.069	0.334	0.437	0.840
26/02	36	14.0	13:44	56.00281	-6.05780	20	48	2.4	50	1.5	71.8	0	21	38	59	12	10	1	0	0.000	0.371	0.671	1.042
26/02	37	14.0	16:11	56.01211	-6.04659	25	67	2.7	45	1.5	99.9	5	35	48	88	5	8	0	0	0.056	0.392	0.538	0.986
26/02	38	13.0	16:45	56.01059	-6.04658	20	65	3.2	37	1.5	97.2	10	73	142	225	6	16	1	0	0.112	0.814	1.583	2.509
26/02	39	14.0	17:12	56.00904	-6.04619	16	57	3.6	33	1.5	86.2	15	96	105	216	5	10	3	0	0.184	1.178	1.288	2.650

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Date	Tow	Depth (m)	UTC Start (h:min)	Lat Mid-tow (deg)	Lon Mid-tow (deg)	Tow Duration (mins)	Tow Length (m)	Av Speed (m min^{-1})	Average Exposure Time (s)	Swath Width (m)	Swept Area (m^2)	Count Whole siliqua Small (Cat 1)	Count Whole siliqua Medium (Cat 1)	Count Whole siliqua Large (Cat 1)	Count Whole siliqua All Sizes (cat 1)	Count Partial siliqua (Cat2)	Count Tops (Cat3)	Count Whole magnus (Cat4)	Count Partial magnus (Cat5)	Mean Dens siliqua Small (m^{-2})	Mean Dens siliqua Medium (m^{-2})	Mean Dens siliqua Large (m^{-2})	Mean Dens siliqua All Sizes (m^{-2})
26/02	40	15.5	17:34	56.00761	-6.04530	17	84	5.0	24	1.5	126.7	4	37	66	107	5	17	1	0	0.037	0.345	0.615	0.997
27/02	41	16.0	10:10	56.01203	-6.06230	21	79	3.8	32	1.5	119.0	10	56	96	162	11	12	0	0	0.093	0.521	0.894	1.508
27/02	42	15.5	10:37	56.01085	-6.05794	18	71	3.9	30	1.5	106.5	17	57	95	169	23	13	1	0	0.183	0.612	1.021	1.816
27/02	43	15.0	11:02	56.00966	-6.05621	19	53	2.8	43	1.5	79.2	4	32	74	110	17	9	10	0	0.058	0.465	1.076	1.600
27/02	44	15.0	11:29	56.00849	-6.05458	15	51	3.4	35	1.5	77.1	14	57	72	143	11	12	1	0	0.204	0.829	1.047	2.080
27/02	45	14.5	11:49	56.00734	-6.05308	17	73	4.3	28	1.5	109.6	11	50	117	178	13	23	8	0	0.116	0.529	1.239	1.885
27/02	46	16.5	12:45	56.00952	-6.06539	19	62	3.3	37	1.5	93.5	11	52	83	146	11	12	8	0	0.131	0.620	0.990	1.741
27/02	47	15.0	13:11	56.00833	-6.06303	17	68	4.0	30	1.5	101.4	5	37	56	98	7	12	5	0	0.057	0.421	0.636	1.114
27/02	48	14.5	13:35	56.00728	-6.06099	16	54	3.4	36	1.5	80.5	6	43	63	112	14	24	4	0	0.095	0.678	0.993	1.765
27/02	49	14.5	14:00	56.00593	-6.05851	19	63	3.3	36	1.5	94.9	2	31	77	110	8	17	4	0	0.025	0.387	0.962	1.374
27/02	50	18.0	14:52	55.99884	-6.08333	18	94	5.2	23	1.5	141.0	9	24	162	195	23	56	5	0	0.085	0.228	1.538	1.851
27/02	51	17.5	15:17	56.00032	-6.08139	22	87	4.0	30	1.5	130.6	7	32	122	161	8	18	11	0	0.061	0.277	1.055	1.393
27/02	52	16.5	15:46	56.00156	-6.07935	13	71	5.4	22	1.5	106.3	7	19	80	106	13	20	3	0	0.082	0.223	0.937	1.242
27/02	53	16.0	16:06	56.00240	-6.07635	18	72	4.0	30	1.5	107.9	3	20	110	133	11	23	7	0	0.034	0.223	1.229	1.486
28/02	54	16.0	09:10	56.01092	-6.04443	20	69	3.5	35	1.5	103.5	6	32	72	110	12	14	1	0	0.068	0.365	0.821	1.254
28/02	55	15.5	09:35	56.01249	-6.04434	18	61	3.4	35	1.5	91.6	10	37	38	85	5	7	1	0	0.121	0.449	0.461	1.031
28/02	56	14.0	10:00	56.01395	-6.04388	18	51	2.8	42	1.5	76.5	10	19	49	78	4	20	3	0	0.166	0.316	0.815	1.297
28/02	57	14.5	10:26	56.01531	-6.04290	17	67	3.9	31	1.5	100.2	30	67	62	159	9	16	6	0	0.337	0.753	0.696	1.786
28/02	58	15.5	10:49	56.01658	-6.04156	17	60	3.5	34	1.5	90.1	28	83	118	229	12	15	6	0	0.339	1.004	1.427	2.769
28/02	59	15.5	11:41	56.00908	-6.06135	20	77	3.9	31	1.5	116.0	19	75	69	163	16	15	3	0	0.187	0.736	0.678	1.600

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Date	Tow	Depth (m)	UTC Start (h:min)	Lat Mid-tow (deg)	Lon Mid-tow (deg)	Tow Duration (mins)	Tow Length (m)	Av Speed (m min^{-1})	Average Exposure Time (s)	Swath Width (m)	Swept Area (m^2)	Count Whole siliqua Small (Cat 1)	Count Whole siliqua Medium (Cat 1)	Count Whole siliqua Large (Cat 1)	Count Whole siliqua All Sizes (cat 1)	Count Partial siliqua (Cat2)	Count Tops (Cat3)	Count Whole magnus (Cat4)	Count Partial magnus (Cat5)	Mean Dens siliqua Small (m^{-2})	Mean Dens siliqua Medium (m^{-2})	Mean Dens siliqua Large (m^{-2})	Mean Dens siliqua All Sizes (m^{-2})
28/02	60	14.5	12:07	56.01054	-6.06021	21	61	2.9	41	1.5	91.8	14	37	60	111	11	18	1	0	0.185	0.488	0.791	1.464
28/02	61	15.5	12:36	56.01211	-6.05872	20	77	3.9	31	1.5	115.7	20	80	65	165	14	16	3	0	0.197	0.786	0.639	1.622
28/02	62	15.0	13:04	56.01358	-6.05702	19	62	3.3	37	1.5	93.0	33	122	152	307	25	35	12	0	0.408	1.509	1.880	3.797
01/03	63	22.5	09:48	55.97500	-6.10529	18	53	2.9	41	1.5	79.1	1	0	0	1	0	1	3	0	0.016	0.000	0.000	0.016
01/03	64	22.5	10:30	55.97786	-6.10293	17	69	4.1	30	1.5	103.3	14	64	8	86	12	11	103	0	0.153	0.699	0.087	0.939
01/03	65	21.5	10:58	55.97932	-6.10082	18	65	3.6	33	1.5	97.1	4	49	56	109	13	12	28	0	0.047	0.579	0.661	1.287
01/03	66	18.5	11:53	55.97692	-6.09505	17	88	5.2	23	1.5	131.6	13	37	71	121	13	17	26	0	0.116	0.329	0.631	1.075
01/03	67	19.0	12:17	55.97844	-6.09414	17	76	4.5	27	1.5	114.0	2	24	60	86	6	20	17	0	0.022	0.259	0.647	0.927
01/03	68	18.5	12:41	55.97994	-6.09284	17	60	3.5	34	1.5	89.6	3	25	84	112	12	16	11	0	0.040	0.330	1.109	1.479
01/03	69	18.0	13:05	55.98127	-6.09117	19	80	4.2	29	1.5	119.9	7	25	87	119	17	11	12	0	0.067	0.241	0.838	1.146
01/03	70	22.0	13:58	55.98495	-6.09845	19	62	3.3	37	1.5	93.1	58	138	3	199	14	13	104	0	0.672	1.598	0.035	2.305
01/03	71	21.0	14:24	55.98621	-6.09663	19	65	3.4	35	1.5	97.0	4	30	171	205	28	28	12	0	0.049	0.370	2.111	2.531
01/03	72	21.0	14:50	55.98763	-6.09510	20	65	3.3	37	1.5	98.0	4	30	211	245	24	36	1	0	0.049	0.366	2.573	2.987
01/03	73	20.0	15:16	55.98916	-6.09453	19	76	4.0	30	1.5	113.3	4	34	197	235	27	37	9	0	0.043	0.363	2.103	2.509
02/03	74	15.0	09:07	55.99545	-6.06837	18	73	4.1	30	1.5	109.6	7	12	50	69	6	9	4	0	0.075	0.128	0.532	0.735
02/03	75	15.0	09:30	55.99389	-6.06926	15	72	4.8	25	1.5	107.5	3	4	21	28	4	8	2	0	0.037	0.050	0.261	0.348
02/03	76	15.0	09:50	55.99220	-6.06964	18	60	3.3	36	1.5	90.3	4	9	28	41	3	5	0	0	0.051	0.116	0.359	0.526
02/03	77	15.5	10:14	55.99044	-6.06907	17	87	5.1	24	1.5	130.2	3	16	34	53	5	11	1	0	0.029	0.154	0.327	0.509
02/03	78	17.5	10:37	55.98908	-6.06763	19	76	4.0	30	1.5	113.5	2	9	28	39	4	11	1	0	0.023	0.105	0.327	0.456
02/03	79	18.5	11:30	55.99482	-6.08872	18	81	4.5	27	1.5	122.0	2	31	201	234	31	38	3	0	0.020	0.312	2.021	2.353

Appendix 1: Summary details of tows on Tarbert Bank.

Date	Tow	Depth (m)	UTC Start (h:min)	Lat Mid-tow (deg)	Lon Mid-tow (deg)	Tow Duration (mins)	Tow Length (m)	Av Speed (m min^{-1})	Average Exposure Time (s)	Swath Width (m)	Swept Area (m^2)	Count Whole siliqua Small (Cat 1)	Count Whole siliqua Medium (Cat 1)	Count Whole siliqua Large (Cat 1)	Count Whole siliqua All Sizes (cat 1)	Count Partial siliqua (Cat2)	Count Tops (Cat3)	Count Whole magnus (Cat4)	Count Partial magnus (Cat5)	Mean Dens siliqua Small (m^{-2})	Mean Dens siliqua Medium (m^{-2})	Mean Dens siliqua Large (m^{-2})	Mean Dens siliqua All Sizes (m^{-2})
02/03	80	18.0	11:54	55.99592	-6.08659	21	73	3.5	34	1.5	110.1	3	25	196	224	19	22	3	0	0.031	0.259	2.028	2.318
02/03	81	18.0	12:21	55.99688	-6.08447	15	65	4.3	28	1.5	97.4	4	17	140	161	14	19	2	0	0.048	0.202	1.667	1.917
02/03	82	17.5	12:42	55.99797	-6.08255	18	62	3.4	35	1.5	92.7	2	14	93	109	9	21	0	0	0.027	0.186	1.238	1.451
02/03	83	17.0	13:05	55.99896	-6.08099	10	34	3.4	36	1.5	50.6	2	4	40	46	4	10	0	0	0.050	0.100	0.997	1.147
02/03	84	15.0	13:48	56.00936	-6.05602	14	65	4.7	26	1.5	97.8	8	54	69	131	16	6	1	0	0.091	0.611	0.781	1.482
02/03	85	14.5	14:09	56.00834	-6.05366	17	69	4.1	30	1.5	103.5	9	56	86	151	21	15	3	0	0.101	0.631	0.970	1.703
02/03	86	14.5	14:32	56.00743	-6.05118	16	67	4.2	29	1.5	100.8	7	52	76	135	20	17	2	0	0.083	0.618	0.903	1.605
02/03	87	16.0	14:55	56.00659	-6.04854	16	75	4.7	25	1.5	113.0	2	61	64	127	12	16	1	0	0.021	0.633	0.664	1.317
03/03	88	21.0	09:26	56.01703	-6.06797	18	75	4.1	29	1.5	111.8	45	219	48	312	32	43	76	0	0.468	2.277	0.499	3.244
03/03	89	20.0	09:53	56.01768	-6.08206	10	42	4.2	29	1.5	62.6	83	214	24	321	0	0	0	0	1.327	3.420	0.384	5.130
03/03	90	19.0	10:31	56.02033	-6.05537	15	76	5.1	24	1.5	114.5	113	190	127	430	0	0	0	0	0.987	1.660	1.109	3.756
03/03	91	19.0	10:54	56.02139	-6.05292	17	81	4.7	25	1.5	120.8	80	149	135	364	0	0	0	0	0.662	1.233	1.118	3.013
03/03	92	18.0	11:43	56.01378	-6.02952	10	39	3.9	31	1.5	58.3	89	271	7	367	0	0	0	0	1.526	4.647	0.120	6.293
03/03	93	17.5	12:02	56.01511	-6.02709	11	42	3.8	31	1.5	62.9	150	266	4	420	0	0	0	0	2.386	4.230	0.064	6.680
03/03	94	20.0	12:46	56.02332	-6.04599	20	74	3.7	33	1.5	110.7	69	136	111	316	0	0	0	0	0.623	1.229	1.003	2.855
03/03	95	20.0	13:12	56.02442	-6.04444	16	78	4.9	25	1.5	116.5	30	28	40	98	0	0	0	0	0.257	0.240	0.343	0.841

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