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Report on razor clam surveys in Largo Bay (Firth of Forth)

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This report presents the results of work commissioned by Marine Scotland.

Report on Razor Clam Surveys in Largo Bay (Firth of Forth)

Dr Clive J Fox, Scottish Association for Marine Science

Executive summary

This report describes a survey carried out in Largo Bay, Firth of Forth in 2020. The original work plan was interrupted due to Covid-19 but a survey of the area currently being fished was completed prior to lock-down. A combination of a commercial electrofishing rig and towed video was deployed using the fishing vessel 'Maxine'. 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. These count data were converted to area densities (numbers of razor clams m^{-2}) based on estimates of the swept area from tow start and end positions recorded from the vessel chart plotter.

Seventy-four tows were completed in and around the main *Ensis* harvesting area in Largo Bay between 28 February 2020 and 20 March 2020. Of these, two tows were excluded from further analysis as the video suggested that the electrical rods had not settled properly onto the seabed leaving 72 valid tows. Average towing speeds varied between 1.9 and 6.1m min^{-1} (mean 3.2m min^{-1}) and estimated swept areas were between 45 to 181m^2 (mean 76m^2). From the video recordings, 20,538 individual *E. siliqua* were counted and 18,439 measured. All razor clams observed on the videos were assigned as *Ensis siliqua* which accords with the skipper's observation that *Ensis magnus* are not found in this area.

Considering all sizes, *E. siliqua* densities of up to 11.0m^{-2} were observed (4.0 ± 2.8 mean ± std dev). For sizes above the minimum conservation reference size (MCRS) of 100mm, densities were up to 9.3m^{-2} with a mean of 3.0 ± 2.2m^{-2} (mean ± std dev). The commercial fishers tend to target *Ensis* above 150mm as these fetch the highest price and densities for this size group were up to 4.9m^{-2} with a mean of 1.4 ± 1.2m^{-2} (mean ± std dev). The size distribution of the razor clams suggested two length modes, one at around 90–100mm and the other around 150–160mm. These likely represent two age classes and while showing that smaller clams are present, the densities of smaller clams were generally lower than for the larger sizes.

Other organisms occasionally seen on the videos were shore crabs, hermit crabs and common starfish. Juvenile flatfish (probably dab or plaice) were only observed on two tows and sandeel (*Ammodytes* spp.) on one tow. Large numbers of eider ducks (*Somateria mollissima*) followed the survey vessel on some days and were

observed on the video diving and taking emerged razor clams from the seabed. The survey vessel skipper suggested that the numbers of eider ducks in the area had increased over recent years. It may therefore be necessary to account for this additional source of mortality when considering sustainable harvest levels for *Ensis* in Largo Bay but estimating this predation pressure was beyond the scope of the present survey.

The use of towed video combined with electrofishing appeared to work well in Largo Bay. The lowest number of tows completed in any one day was four but this was due to worsening weather conditions and under good conditions up to 11 tows were completed each day. The video recorded was generally of sufficient quality to allow identification of objects on the seabed with only a few tows having parts of the field of view obscured by sediment kicked up by the camera sled. Although the efficiency of the electrofishing equipment is assumed to be high, this has not been formally confirmed by comparison with other methods such as dredging (Hauton et al., 2007). The estimates of *E. siliqua* densities provided in this report therefore represent a minimum for the razor clam stock in Largo Bay in 2020.

Part 1 – Materials and methods

Introduction

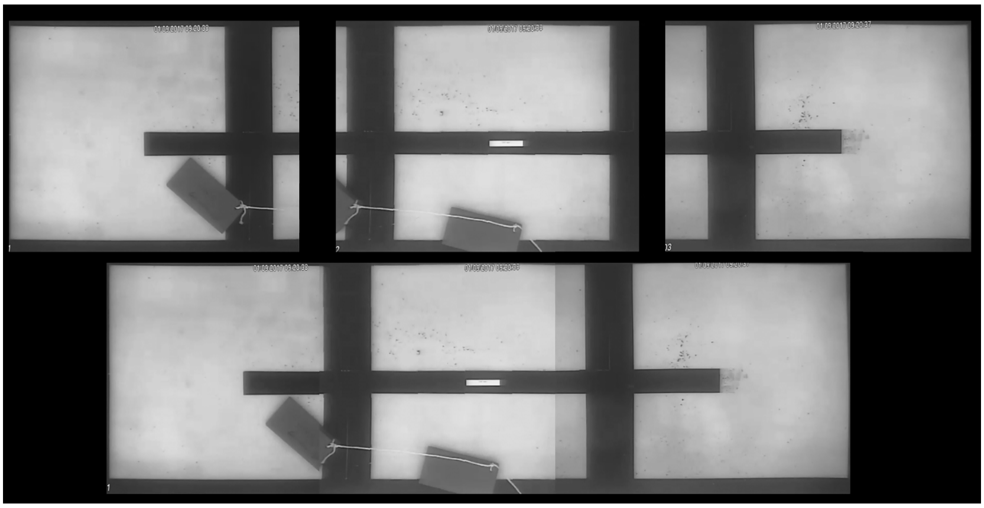
The aim of this survey was to use a combination of electrofishing with towed video to assess the quantities and sizes of razor clams (*Ensis* sp) in Largo Bay, Firth of Forth. This is one of a series of surveys to collect data on the distribution and abundance of razor clams in areas where razor clam harvesting is permitted under a Scottish Government trial on electrofishing (Scottish Government, 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 so that fishers recognise specific areas or beds where fishing is worthwhile. Predetermined randomised surveys covering the whole of the production area are therefore not likely to yield particularly useful information because much of the area is not suitable habitat. The present survey made extensive use of local fisher knowledge, as well as fishing location data collected by Marine Scotland, to target the part of the production area which has been regularly fished over the first two years of the trial. In addition, some tows were conducted outside of this regularly fished area for comparison.

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 video cameras mounted on a sled which is towed behind a commercial electrofishing rig. The video data are monitored and recorded on the towing vessel. 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. Prior to the fieldwork, the video cameras were calibrated in the seawater test-tank facility at the Scottish Association for Marine Science (SAMS) laboratory, Dunstaffnage, Oban. The conversion factor from video pixels to mm was estimated to be 1px = 1.09756mm and the error in the central calibration bar (Figure 1) was estimated to be 4mm or 0.4% over a 1m length.

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 1.5m in the lower panel. Plastic calibration blocks are shown on top of the calibration targets, each block is 15cm in length, each calibration square is 45cm internally and the horizontal bar is 1m in length.



As a further check on the accuracy of reconstructing object sizes from the video, two 150mm long, plastic blocks were recorded at various locations within the field of view in the test tank (Figure one). Thirty measurements of the blocks at different locations in the field of view were collected from the post-processed video. Compared to the known calibration block length, the reconstructed lengths showed a small positive bias of 1.5mm, close to that reported in Fox (2017). 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. However, all the reconstructed calibration block measurements were within 1cm of the true block lengths (the mean of the reconstructed measurements = 151.5mm, std dev = 3.6mm, n = 30). The impact of varying object distance from the cameras was tested and reported in Fox (2017) where it was concluded that major errors in reconstructed lengths of individual razor clams were unlikely, unless there were large undulations (>5cm) in the seabed leading to substantial variations in the distance between a camera and the target. However, the height of sand ripples in the field will generally be smaller than 5cm, so such errors are unlikely. Reconstructed razor clam lengths from field collected video are therefore expected to have an accuracy of ± 1cm of their true length.

Largo Bay field survey

The survey was conducted from the fishing vessel 'Maxine' (ML129; registry C19929, D. Leadbetter & Son Shellfish Ltd., Figure 2) skippered by Mr David Leadbetter. The video rig was towed 3m behind the normal commercial electrofishing rig used on 'Maxine'. The electrofishing rig consists of a 5m wide plastic spreader bar fitted with three pairs of brass electrodes, each 2.6m in length with 1m separation between positive and negative electrodes. Power was supplied using an inverter box as 24V AC at around 50-80 amps per electrode pair in line with the electrofishing equipment regulations stipulated by the Scottish Government for the trial. All experimental fishing took place under a specific survey derogation issued by Marine Scotland Licencing.

Figure 2: Fishing vessel 'Maxine' in Anstruther harbour, from where the surveys were conducted. © D. Leadbetter & Son Shellfish Ltd

According to the skipper, the vessels fishing in Largo Bay under the trial originally focussed in the northwest corner of the dark pink area shown in Figure 3, but latterly decided co-operatively to spread their effort over a wider area. This spatial shift was also evident in vessel track plots compiled by Marine Scotland, comparing 2018 and 2019. This spreading of effort may have been triggered by a reduction in catches of larger razors in the north-western corner of the area, but alternatively by a desire of the skippers not to concentrate fishing effort in too small a sub-area of the permitted box. Furthermore, if all vessels are working within a small area they tend to get in each other's way, so there is an additional incentive to spread effort. Some additional survey tows were undertaken just outside the shellfish waters Class A boundary, to the southeast of the main fishery area and to the west, off Leven. Information on razor densities outside of the main fished area is of interest for comparison with densities in the main fished area.

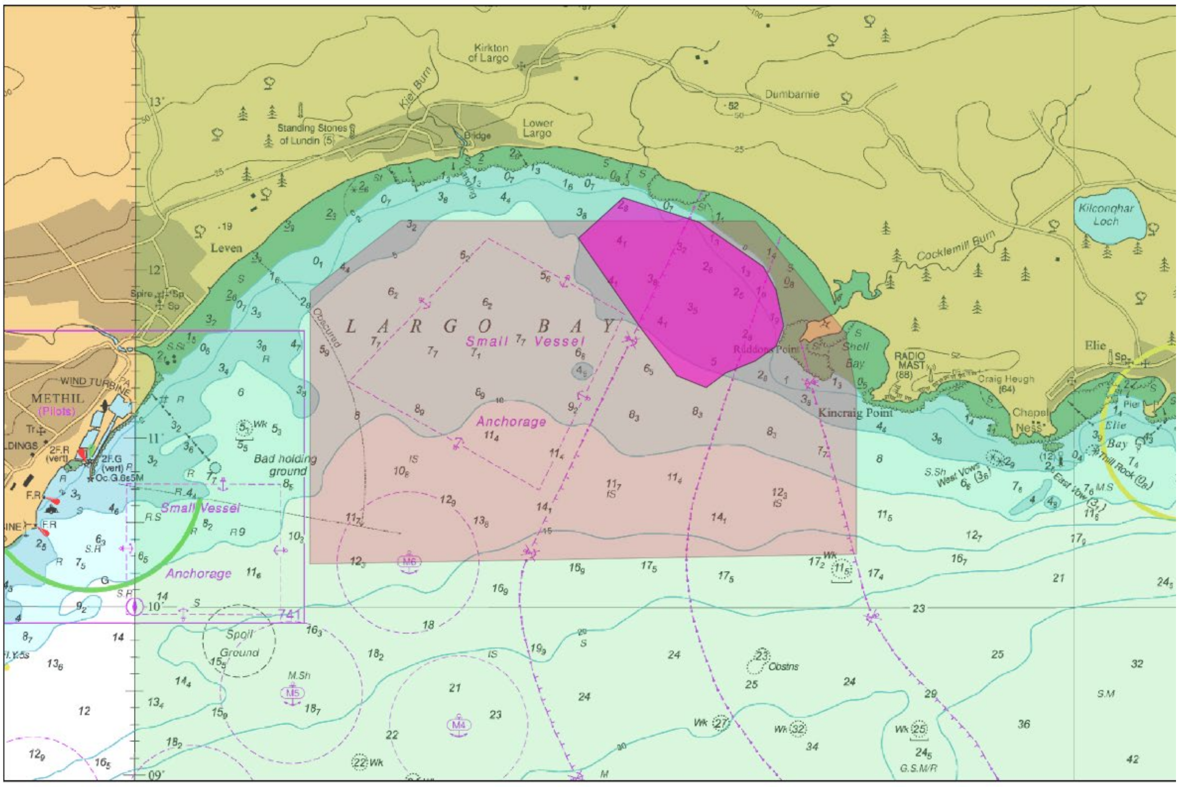


Figure 3: Largo Bay, the light green area indicates the northern part of the wider Firth of Forth razor trial area, light pink indicates the Food Standard Agency Shellfish Class A waters for razors in Largo Bay, the darker pink region encompasses the majority of the fishing fleet tracks for the last two years. Areas with known hard ground or snagging hazards off Methil are marked “Bad holding ground” on the chart. Underlying chart © Crown Copyright/HR Wallingford Ltd. 2017. All Rights Reserved. Licence No. L012017.0001. Not to be used for navigation.

The fishing vessel ‘Maxine’ can safely operate to about 4m water depth so shallow stations were targeted around high tide. Maximum fishing depth was around 10m due to the length of electrode cables available, so deeper locations were surveyed at low tide. The fishery rarely works at water depths greater than 10m due to the limits on air-based SCUBA diving. ‘Maxine’ fishes without a clump weight and therefore relies on a combination of tide and wind to set the direction of the tow. Briefly the fishing operation involves dropping an anchor and then reversing the vessel whilst paying out a cable until the vessel is between 100 and 150m from the anchor. Once the vessel has settled down, the electrofishing gear is set and the vessel then slowly warped back 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 and using a plot of the previous tow locations to visually identify gaps in coverage. 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.

The normal deployment of anchor and warp was followed but once the warping winch was started, the video camera rig was lowered (Figure 4) followed by the electrofishing rig.

Figure 4: The video-rig being lowered off the back of the vessel from the fixed stern derrick, the grey bar resting on the gunwhale is the electrode spreader which was lowered once the video rig had settled on the seabed, the black video cables and orange electrofishing power cables can also be seen.

As well as the three downward facing cameras, the video rig has a forward-facing camera which was used at the start of each tow to assess whether the gear had deployed correctly and whether the seabed type was suitable for the tow. Rough ground was only encountered on a few tows which were conducted outside of the area in which the fishery has been concentrated. Forward visibility was generally rather poor as there were a number of periods of bad weather just before each survey which had increased the levels of sediment in the water (Figure 5). However, because of the short distance between the downward facing video cameras and the seabed, this turbidity did not generally affect the quality of the video images of the seabed.

Figure 5: Image from the forward-facing camera on 26 February 2020. One of the towing ropes is just visible on the lower right-hand side of the image with the camera cables and video-rig lifting line above. Although the seabed immediately in front of the video camera is visible along with emerged razor clams, the high turbidity is obscuring the electrode separator bar which was 3m in front of the camera.

Once correct deployment of the gear was confirmed (Figure 6), the power to the electrofishing rig was turned on and the survey tows commenced.

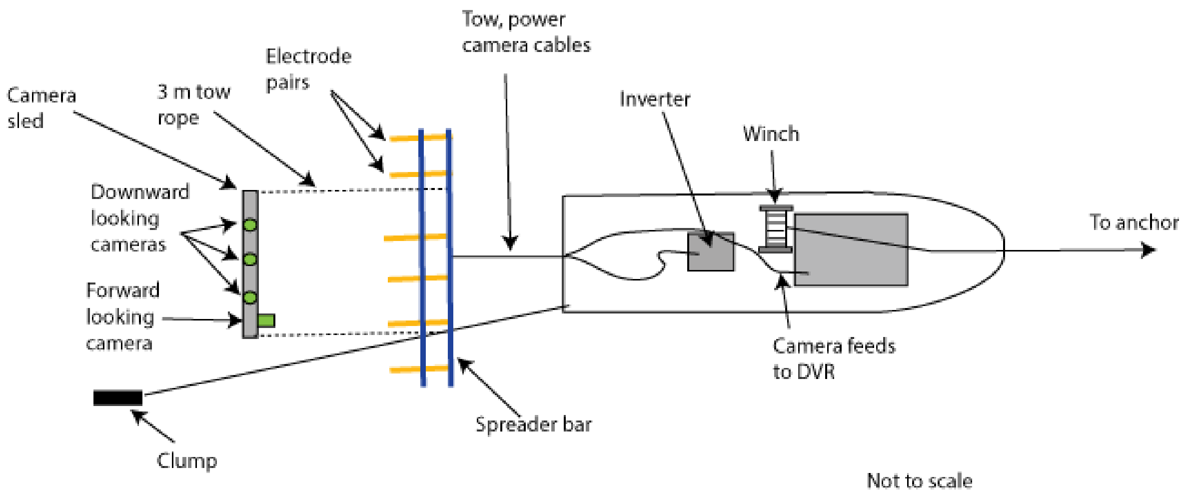


Figure 6: Diagram illustrating how the electrofishing gear and towed camera sled are typically deployed. Note that 'Maxine' operates without the clump weight shown in the diagram.

Video was monitored continuously during the tow (Figure 7) and recorded using a digital video recorder (Hawk D1/960H AHD RF3089, RF Concepts, Belfast UK).

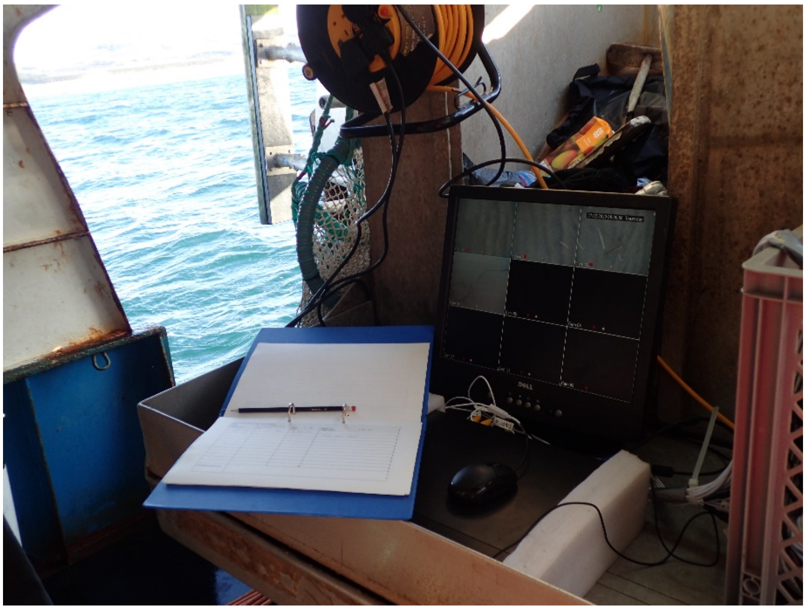


Figure 7: Video data being monitored and recorded on 'Maxine', the monitoring screen with the live pictures is visible in front of the blue folder.

Water column parameters (temperature and salinity) were recorded daily from the surface to the seabed using a CastAway CTD (Sontek).

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 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).

In order to convert the counts to area-based densities, estimates of tow length are required. There are two methods available for estimating tow lengths. Firstly, they can be 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. Secondly, tow lengths can be estimated by vertically stitching the video from one of the camera feeds as described in Fox (2017). However, comparison of results from both approaches in previous surveys has suggested good agreement but the video-stitching process is much more time-consuming and does not work if there are insufficient identifiable markers on the seabed. Estimates of tow distances were therefore based on the recorded GPS positions for the start and end of each tow. Because the survey vessel is continually warped towards the holding anchor during the tow, it was assumed that tows were straight-lines.

The camera alignments and video processing were set up so that the total imaged swath was 1.5m wide and thus the swept areas (m^2) were estimated as tow lengths multiplied by 1.5. Razor clams on the videos were assigned to one of three classes: Class one - whole *Ensis siliqua* lying flat on the seabed; Class two - *E. siliqua* lying flat on the seabed but overlapping the edge of the video frame so that only part of the shell was visible; Class three - *E. siliqua* tops where the clam had not fully emerged but was completely within the video frame. For class two it was assumed that each count would represent half an individual (since on average half an individual count would lie in the adjacent area outside the field of view). The measurement data for class two were not used further. For class three, each record was counted as one individual but the measurement data were not used further.

Estimation of *Ensis* densities in Largo Bay

As no *E. magnus* were identified (and also confirmed by the skipper as not being found in Largo Bay), only data for object classes one, two and three from the videos were analysed further. To obtain the count of *E. siliqua* (all sizes) on tow $_i$:-

E. siliqua $_i$ = count class one $_i$ + count class two $_i$ *0.5 + count class three $_i$ [1]

When considering the counts and densities of *Ensis* above a certain length, the count of class two and three objects is meaningless (because their true size 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 object classes would be the same. Therefore the total count of *Ensis* above size $_z$ on tow $_i$:-:-

E. siliqua $_{>z,i}$ = count class one $_{>z,i}$ + (count class two $_i$ + count class three $_i$) * (class one $_{>z,i}$ / class two $_i$)
[2]

The total counts for each tow were then converted to density estimates (nos m^{-2}) by dividing by the estimated swept area of that tow (m^2).

Data were mapped using using QGIS (version 3.10.9) and other statistical calculations performed using R (version 3.3.2).

Results

Overview of results

The video equipment generally worked well settling into the correct configuration as a result of tension on the ropes connecting the camera rig to the spreader bar combined with the slow forward movement of the vessel. On a few occasions the equipment did become tangled and had to be re-set. Individual tows lasted around 15-20 minutes, except on a few occasions when the tow had to be terminated early due to concerns about deteriorating sea state.

There was little variation in the physical water column properties between the different survey days. Water temperatures were between 6.0 and 6.6 ºC and salinity between 33 and 33.7 (Figure 8 and Figure 9). Lower surface salinities were noted in March but below 2m depth the water column was well mixed – as expected for this inshore tidal location.

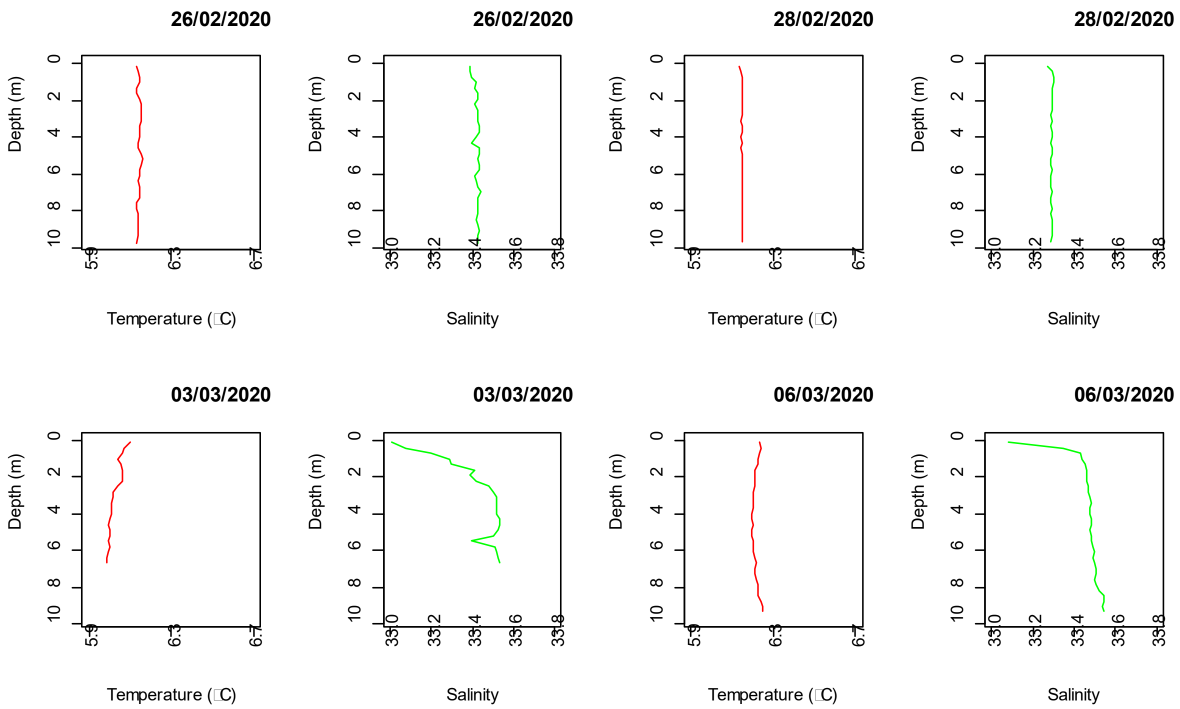


Figure 8: CTD profiles from 26 February 2020 and 28 February 2020, and 3 March 2020 and 6 March 2020 in Largo Bay

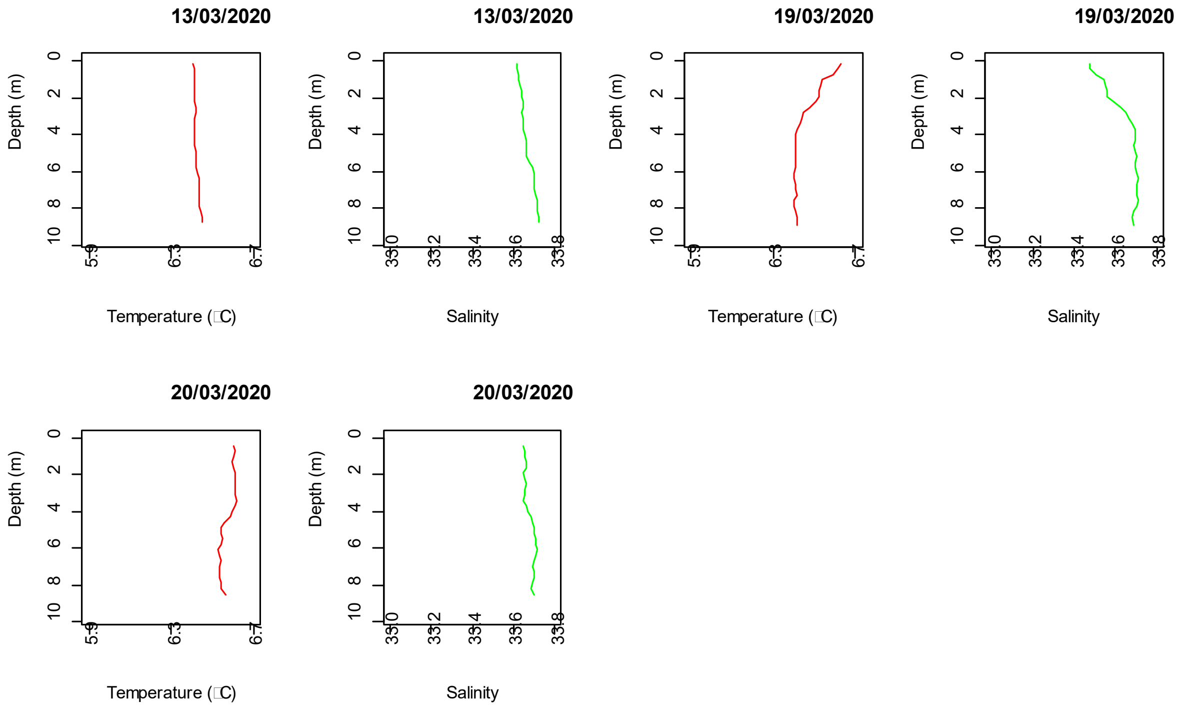


Figure 9: CTD profiles from 13 March 2020, 19 March 2020 and 20 March 2020 in Largo Bay

Tow speeds varied between 1.9 and 6.1m min^{-1} (3.2 ± 0.71 mean ± std dev). GPS-based swept areas for the video were estimated to be between 45 to 181m^2 with the average being 76m^2 (Figure 10). The single tow with a swept area exceeding 150m^2 was due to the tide increasing and moving the survey vessel further than intended (Tow 11).

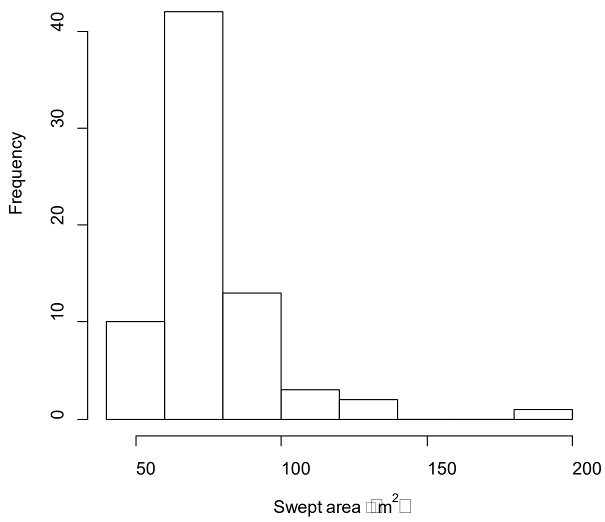


Figure 10: Distribution of swept areas across all the tows undertaken in the Largo Bay survey.

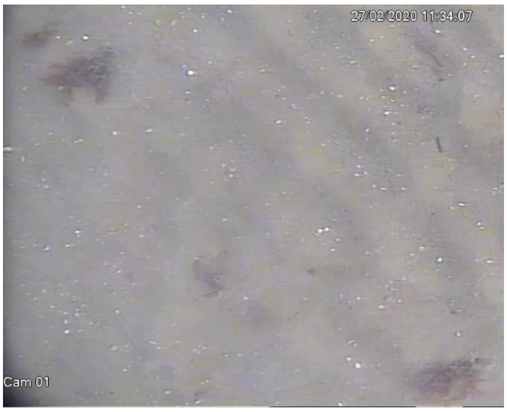
From the video observations, the sediments in Largo Bay consist of fine sand mixed with well ground shell fragments. Small sand ripples were present on nearly all tows (Figure 11). Remains of broken razor clam shells were quite common and may be the result of predation by eider ducks (see Discussion). Although sediments did appear a little coarser off Methil, there did not seem much noticeable variability within the area where the fishery has been concentrated (dark pink area in Figure 3).

Figure 11: Representative images of the seabed in Largo Bay (a) tow one – rippled sand with ground shell fragments and emerged razor clam (b) tow six – slightly rippled sand with small stones, an urchin and kelp fragments (c) tow 10 – rippled fine sand with small pieces of unattached weed (d) tow 55 – fine sand with occasional ground shell fragments, few sand ripples.

(a)

(b)

(c)



(d)

Considering all sizes across all the survey tows, densities of *E. siliqua* estimated from the video tows ranged from 0 (although this was only observed on two tows), to a maximum of 11.0m^{-2} (mean ± std dev, 4.0 ± 2.8). For sizes above the minimum conservation reference size (100mm), densities were up to 9.3m^{-2} (mean ± std dev, 3.0 ± 2.2) (Table S 1). The commercial fishers tend to target *Ensis* above 150mm in length as these fetch the highest price and densities for these sized razor clams were up to 4.9m^{-2} (1.4 ± 1.2 mean ± std dev).

Razor clam size distributions

Pooling the razor clam length data (class one objects) from all the tows suggests there were two size modes, one at around 90–100mm and the other around 150–160mm (Figure 12).

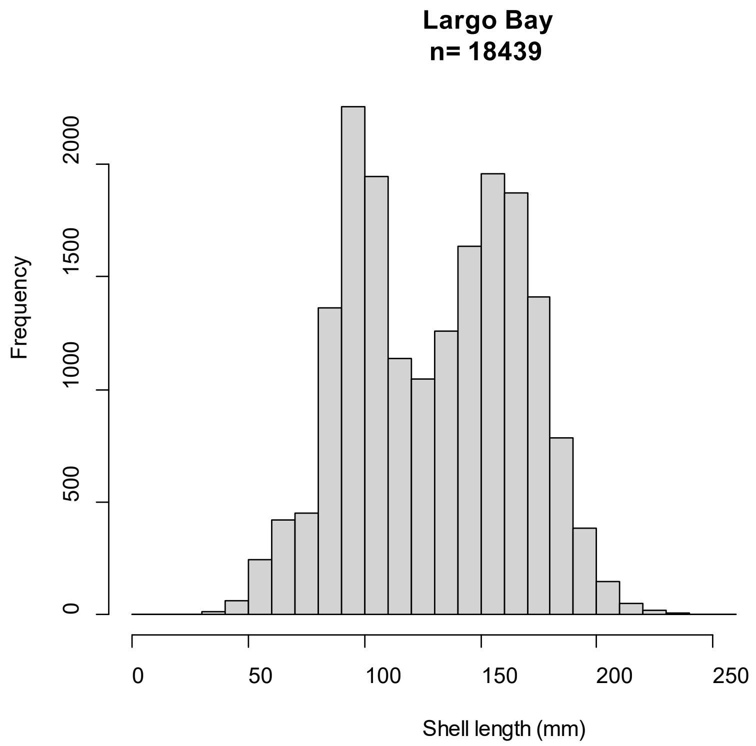


Figure 12: Frequency histogram for E. siliqua reconstructed lengths from all the video tows.

The spatial density distribution of the razor clams is shown in Figure 13 and Figure 14. It should be noted that the tidal elevation in Largo Bay is up to 6m above chart datum on spring tides and 2–4m above chart datum on neaps, so one needs to add approximately 3m to the charted depths to derive the average water depth over a whole tidal cycle at a tow location.

Considering *Ensis* larger than the desirable commercial size of 150mm (Figure 13), higher densities of these larger sizes were spread across the main fished area but with a suggestion of lower densities moving into the north-eastern corner. Sampling of the south-eastern corner of the main fished area, adjacent to Ruddons Point, was avoided due to the presence of the gas pipeline marked on the chart, although vessel track information collected by Marine Scotland does show some fishing activity has occurred over this feature. Some tows with higher densities of larger sized *Ensis* were also found just outside the southwestern edge of the main fished area, but low densities of all sizes occurred moving out into water deeper than about 11m (average depth). The area lying immediately to the west of the main fishing area consists of coarser sediments and is not currently exploited by the fishery. Razor clams of commercially desirable sizes were also found just off Leven, but in a rather small patch. The skipper stated that although vessels might have historically occasionally ventured into that patch, as it is somewhat sheltered from westerly winds, the area is littered with obstructions, such as old anchors and moorings. Because of the likelihood of snagging seabed obstructions, this patch is unlikely to be a popular choice for electrofishing. A limited number of survey tows were also conducted to the east of the main fishing area, off Kincraig Point, which revealed moderate densities of *Ensis* of desirable sizes. This location is however subject to stronger tidal currents which limits the time it can be fished, compared to the main fishing area.

Ensis smaller than the MCRS of 100mm were found throughout the surveyed area (Figure 14), but at generally lower densities than for the larger sizes. There did not seem to be any obvious pattern for higher densities of smaller razors around the edges of the main bed, as has been reported in the literature from some other sites (Fahy and Gaffney, 2001).

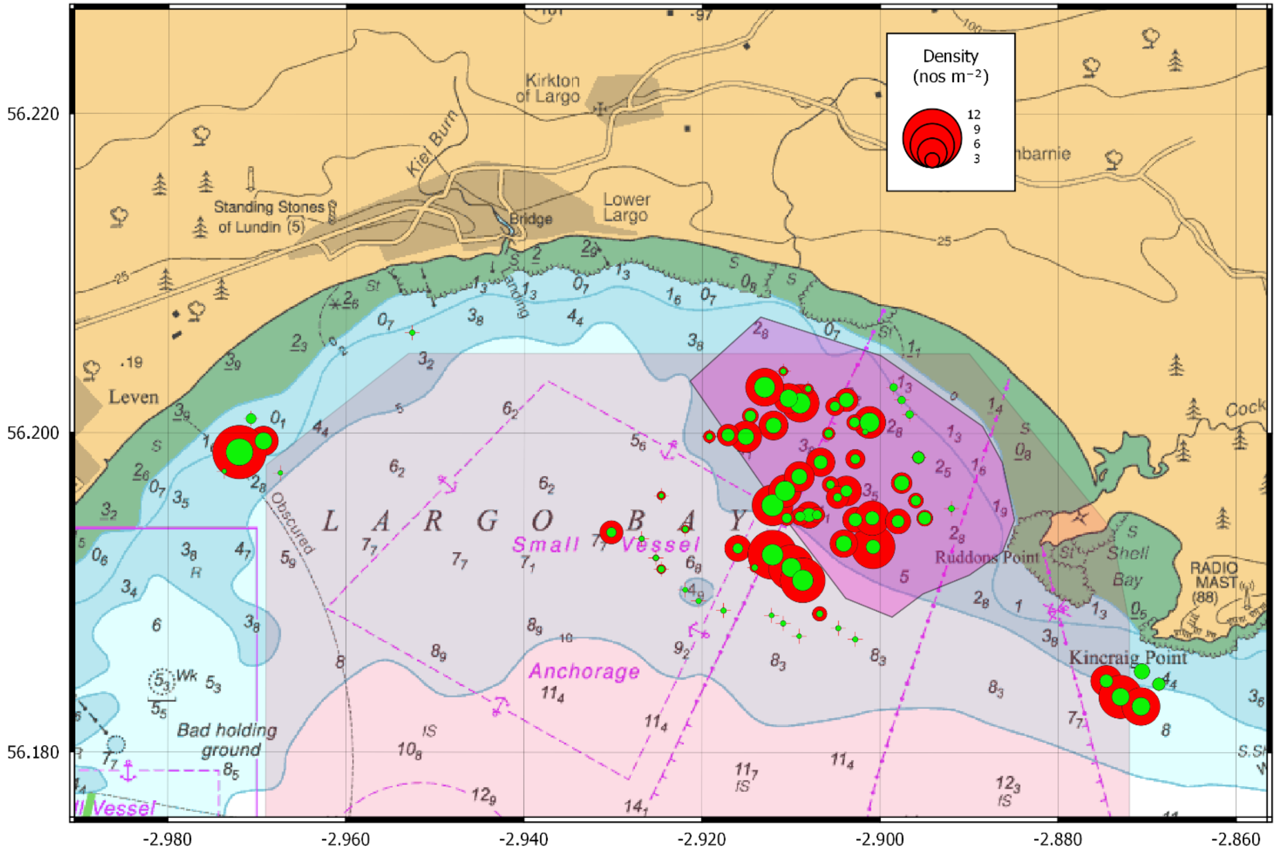


Figure 13: Spatial density distribution of E. siliqua – red circles are densities of razor clams of all sizes; green inset circles are densities of razor clams larger than 150mm. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-point of the video tow. The light pink area indicates the Food Standard Agency Shellfish Class A waters for razors in Largo Bay, the darker pink region encompasses the majority of fishing vessel tracks from 2018 and 2019. Underlying chart © Crown Copyright/HR Wallingford Ltd. 2017. All Rights Reserved. Licence No. L012017.0001. Not to be Used for Navigation.

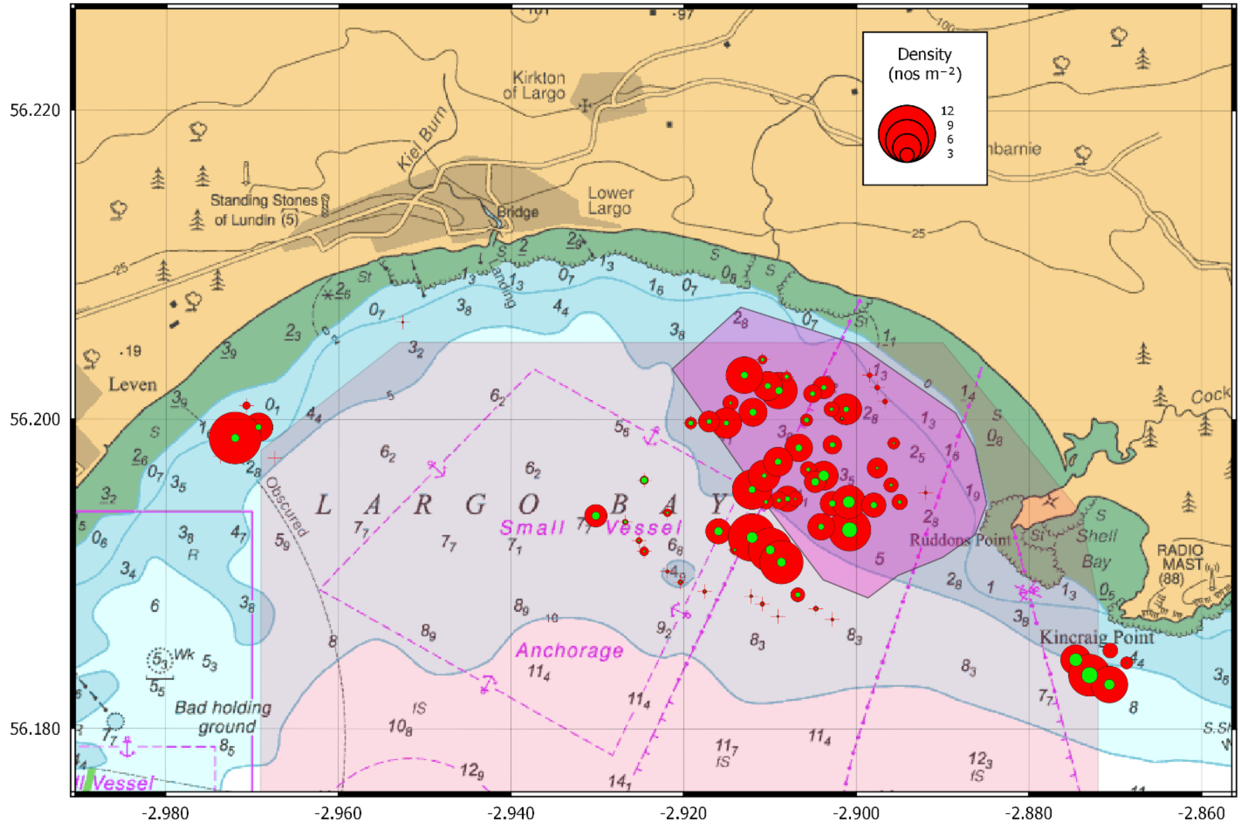


Figure 14: Spatial density distribution of E. siliqua – red circles are densities of razor clams of all sizes; green inset circles are densities of razor clams shorter than the MCRS of 100mm. The diameters of the circles are linearly proportional to the average densities of razor clams in that size range plotted at the mid-point of the video tow. The light pink area indicates the Food Standard Agency Shellfish Class A waters for razors in Largo Bay, the darker pink region encompasses the majority of fishing vessel tracks from 2018 and 2019. Underlying chart © Crown Copyright/HR Wallingford Ltd. 2017. All Rights Reserved. Licence No. L012017.0001. Not to be Used for Navigation.

Razor clam emergence and depth distribution

The depth distribution of smaller *Ensis* 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 and Gaffney, 2001). If correct, shallow areas would only be accessible to commercial electrofishing at the highest tides while deeper areas would not be accessible due to the limitation on dive times when using air scuba equipment. These areas could therefore provide a *de facto* protected source for new recruits to the fished beds.

The percentage of *Ensis* which were only partially emerged may provide an indication of the efficiency of the electrofishing rig. For Largo Bay the percentage of partial emergence was generally less than 15% but higher levels were seen on four of the deeper tows (Figure 16).

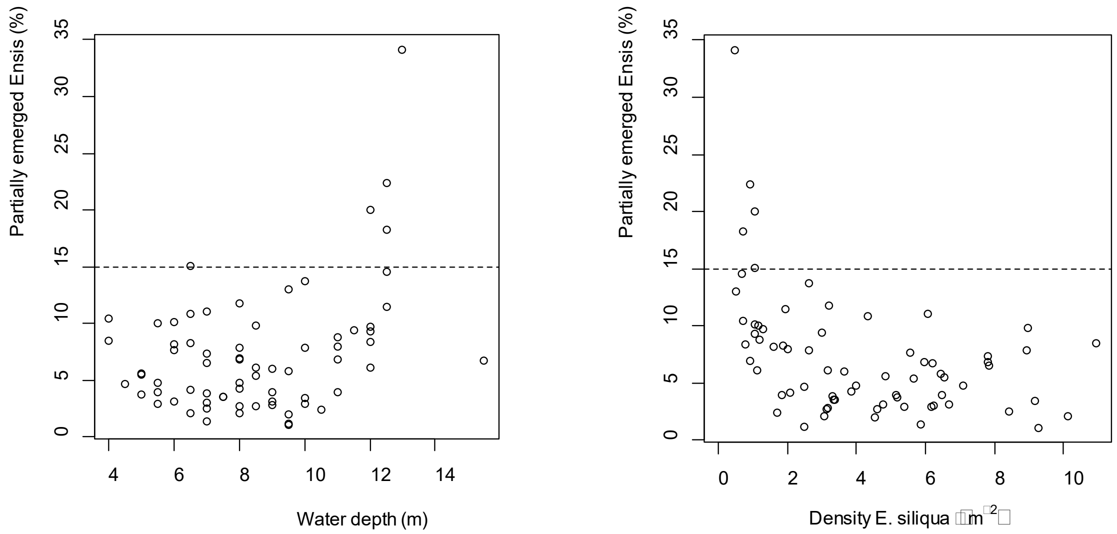


Figure 15: The percentage of razor clams which were partially emerged in each tow plotted against the water depth at the time of the tow (left panel) and density of Ensis (right panel).

The four tows where partial emergence was above 15% (57, 71, 73 and 74) were also ones with low *Ensis* density (Figure 15). This could indicate that the electrical rods had not completely settled on the seabed because these tows were conducted at the depth limit of the electrical cables available during the survey.

The four tows where partial emergence was above 15% were excluded before plotting the densities of small *Ensis* (< 100mm length) against water depth. The density of smaller *Ensis* did not show any obvious pattern with water depth (Figure 16). It should be noted that these data have not been corrected to chart datum or average tidal elevation i.e. the depths shown are those recorded at the time of sampling from the vessel depth sounder. However, whilst correcting to average depths would have the effect of reducing the depths for the shallower samples (because these were sampled around high tide) and increasing the depths for the deeper samples (because these were sampled around low water), this would not alter the overall lack of pattern.

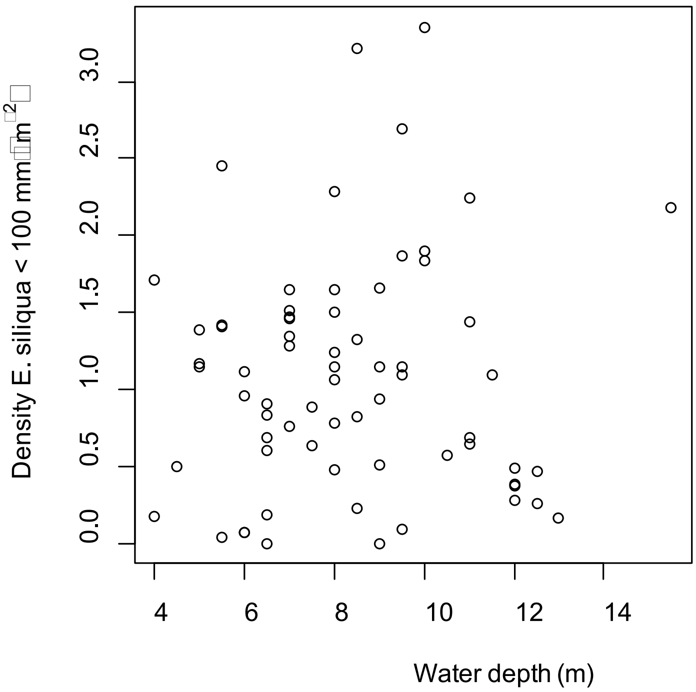


Figure 16: Relationship between densities of E. siliqua below 100mm length against water depth at time of surveying. Note that the four tows where partial emergence was > 15% have been excluded from this plot.

Incidental observations

Starfish were the most common incidental organism observed on the videos, followed by shore crabs. Only two juvenile flatfish and a single small sandeel were observed on the recordings (Table 1). Of note up to 100 eider ducks followed the survey vessel on some days and were observed on the video diving and collecting emerged razor clams from the seabed (Figure 17).

Table 1: Counts of incidental organisms by date from Largo Bay videos.

	03/03	05/03	06/03	06/06	03/03	09/03	20/03	26/02	27/02	28/02
Brittlestar	-	-	-	-	-	7	-	1	-	-
Crab (hermit)	3	1	1	1	-	-	-	-	-	-
Crab (shore)	9	8	7	2	5	25	15	1	1	3
Duck (eider)	3	11	28	-	4	8	13	-	1	-
Duck (mallard)	-	-	-	-	-	1	1	-	-	-
Empty razor shell	-	-	-	-	16	5	-	-	-	-
Flatfish (juvenile, stunned)	-	-	-	-	1	-	1	-	-	-
Sandeel (stunned)	-	-	-	-	1	-	-	-	-	-
Starfish	12	2	9	3	42	106	66	13	13	2
Kelp	-	-	-	-	-	-	-	1	-	-
Turret shell	-	-	-	-	-	1	-	-	-	-
Sea urchin	-	-	-	-	-	1	-	2	-	-
Whelk	-	-	-	-	-	1	-	-	-	-

Figure 17: Eider ducks observed from the forward-facing video camera searching for emerged razor clams on the seabed.

Discussion

There are only a limited number of historical estimates of razor clam densities with which to compare the present findings. McKay (1992) conducted surveys for a variety of shellfish species around the Scottish coast using a suction dredge, but did not survey in the Firth of Forth. At Gormanstown in Ireland, Fahy and Gaffney (2001) reported catches in commercial dredges and estimated the mean density of *E. siliqua* to be 1.45m^{-2}. 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 a number of razor clam surveys using the combined electrofishing towed-video approach have been conducted on the Scottish west coast by Fox et al. (2017, 2018, 2019). From these, the maximum densities of *E. siliqua* recorded to the north of Barra were around 3m^{-2} whilst along the Ayrshire coast only a few tows reached as high as 1m^{-2}. In contrast, the maximum density found in the present study for Largo Bay was 11m^{-2} and the average density across all the tows was 4m^{-2}. The surveys also revealed some tows with reasonable densities of commercial sized *Ensis* outside of the area where fishing has been concentrated in Largo Bay in 2018 and 2019. Whilst the surveys were being conducted it was observed that some vessels in the fishery were beginning to explore these areas, for example off Kincraig Point.

Mapping the densities of smaller *Ensis* (< 100mm length) showed that whilst smaller razor clams were distributed across the survey area, their density declined markedly in water deeper than around 11m (average depth). Even excluding the four tows where the percentage of partial emergence was high, which could indicate that the electrical rods had not settled fully on the seabed, there was no evidence that a reservoir of smaller *Ensis* exists in deeper water which can replenish the main bed. It would however be worth investigating even further out but this will require longer electrical cables than were available for the current survey.

Tow speeds in the present surveys (2–6m min^{-1}) were higher than reported in Fox (2017) when using the fishing vessel ‘Lizanna’. The reason for the difference is due to the method of moving the vessels whilst towing. On ‘Lizanna’ the warp was paid out gradually by-hand over the pot-hauling drum with the vessel being moved backwards from the anchor point by the wind and tide. On ‘Maxine’ the vessel was drawn towards the anchor by warping using the hydraulic winch which results in slightly faster speeds compared with relying on wind and tide alone to move the vessel. Although faster speed over the ground will result in shorter exposure times to the electrical field, the tow speeds in the present study were within the range reported for previous trials of electrofishing by Murray et al. (2014), on surveys along the Ayrshire coast (Fox 2018) and are similar to the speeds used in the commercial fishery.

Fox (2018) suggested that the percentage of razor clams which were only partially emerged might provide an index for how efficiently the gear is fishing. For studies along the Ayrshire coast, this percentage averaged 25% but was as high as 60% on some stations in Culzean Bay. In the present survey, the percentage of razors which were partially emerged was generally less than 15%. Because the Ayr coast and Largo Bay tows were conducted at similar towing speeds, these results lend further support to the hypothesis that emergence can be affected by differences in sediment type, rather than towing speed per se. The higher percentages of partial emergence noted on four of the deeper tows conducted in Largo Bay may be explained by the lengths of the electrical cables which, at these depths, were close to their maximum extent. In future surveys, cable extensions should be used to allow deeper tows to be conducted.

Accurate estimation of tow lengths remains an area of the methodology which could be improved. Although the accuracy of the vessel's GPS used in this study is unknown, values of ± 5m are often quoted (https://www.gps.gov/systems/gps/performance/accuracy/). Fixed errors in tow length, such as might be expected from GPS-based navigation systems, will have proportionally more impact when the tow length is small. Thus, an accuracy of ± 5m could result in tow length errors of up to 5% on a 100m long tow but 10% on a 50m long tow. On the other hand, when razor clam densities are around $1m^{-2}$ simulations suggested that tow lengths longer than 50–60m do not substantially increase the precision of the final density estimations providing at least 10 tows are undertaken within a strata (Fox et al., 2019).

One final difference between the method described in Fox (2017) and more recent surveys (Fox 2018, and this report) was that divers were not used to assist with deploying the equipment. The method of deploying the towed video and electrofishing rig from the aft derrick worked well on most occasions and results in lower overall survey costs since a dive team is not required. The video gear only became entangled on a few occasions and was quickly recovered and reset. However, not all fishing vessels in the electrofishing trial are equipped with an aft derrick and this may limit which vessels can be chartered to conduct future surveys.

Murray et al. (2014) mentioned the possibility that stunned razor clams might be predated on the seabed before they have a chance to rebury. If this occurs at a high rate to under-sized clams, which are left on the seabed by the commercial divers, this could impact the sustainability of the stock. However, the numbers of benthic predators seen on the videos from Largo Bay appeared relatively low, and we have only ever observed a few instances of shore crabs consuming stunned razor clams. In contrast, eider ducks may be important predators on razor clams in Largo Bay. Verbal information from the survey skipper suggested that eiders have increased in the area over the past few years, which may mean they are directly benefitting from this fishery.

The data collected in this survey provides a baseline with which to compare *Ensis* densities and sizes from future surveys in Largo Bay. Furthermore, combining these data with growth curves specific to Largo Bay (which are the subject of current research) will allow more accurate estimates of sustainable yields for this area to be produced.

Table S 1: Tow details, counts for E. siliqua from tow videos and estimates of clam density by size groups.

Tow	Date	Time start	Duration (mins)	Depth (m)	Mid-tow Lat (dec deg)	Lon (dec deg)	Swept area (m^2)	Class1	Class2	All sizes Density (nos m^{-2})	Total	Density (nos m^{-2})	>100 mm Density (nos m^{-2})	>150 mm Density (nos m^{-2})
1	26/02/20	08:54	15:59	5.0	56.2021	-2.9038	75.9	338	16	21	367	4.8	3.7	2.2
2	26/02/20	10:12	20:53	5.0	56.2007	-2.9012	77.0	454	43	29	505	6.6	5.4	3.2
3	26/02/20	12:50	13:23	9.0	56.1975	-2.9674	62.2	0	0	0	0	0.0	0.0	0.0
4	26/02/20	13:47	16:56	7.0	56.1995	-2.9693	74.5	379	41	52	452	6.1	4.8	2.7
5	26/02/20	14:52	20:20	6.0	56.2009	-2.9707	95.2	118	40	14	152	1.6	1.5	1.2
6	26/02/20	15:57	16:02	9.5	56.2063	-2.9526	86.2	33	7	6	43	0.5	0.4	0.2
7	27/02/20	08:55	20:22	15.5	56.1964	-2.9038	108.7	602	51	47	675	6.2	4.0	1.5
8	27/02/20	09:40	20:07	6.0	56.1949	-2.9080	124.2	613	44	54	689	5.5	4.4	2.0
9	27/02/20	11:01	14:58	4.0	56.1988	-2.9720	81.5	777	74	79	893	11.0	9.3	4.9
10	27/02/20	11:34	13:53	6.5	56.1976	-2.9737	84.8	0	0	0	0	0.0	0.0	0.0
11	28/02/20	09:05	19:59	4.0	56.1953	-2.8920	181.4	109	11	14	129	0.7	0.5	0.3
12	28/02/20	10:15	16:58	4.5	56.1985	-2.8957	66.1	147	16	8	163	2.5	2.0	1.5
13	28/02/20	13:18		8.5	56.1948	-2.9129		Invalid tow						
14	28/02/20	13:46		8.5	56.1936	-2.9115		Invalid tow						
15	03/03/20	08:27	13:58	9.0	56.1949	-2.9071	76.1	223	22	7	241	3.2	2.7	1.0
16	03/03/20	08:55	14:59	9.0	56.1948	-2.9090	65.2	211	25	15	239	3.7	2.7	1.1
17	03/03/20	09:20	14:59	8.5	56.1947	-2.9105	79.0	230	22	7	248	3.1	2.3	1.1
18	03/03/20	10:13	15:03	8.0	56.2005	-2.9120	68.7	367	28	29	410	6.0	4.5	2.4
19	03/03/20	10:50	15:01	7.5	56.2011	-2.9146	74.1	231	15	9	248	3.3	2.7	1.4
20	03/03/20	11:44	14:59	7.0	56.2019	-2.9090	67.6	472	43	36	530	7.8	6.2	3.5
21	03/03/20	12:06	15:05	7.0	56.2022	-2.9103	61.7	356	32	12	384	6.2	4.9	2.9
22	03/03/20	12:41	15:02	7.0	56.2029	-2.9130	72.2	498	45	43	564	7.8	6.3	3.5
23	03/03/20	13:30	14:58	6.5	56.2028	-2.9081	56.6	109	6	5	117	2.1	1.2	0.4
24	03/03/20	14:00	14:59	6.5	56.2039	-2.9109	81.7	134	11	13	153	1.9	1.0	0.3

Table S 1: Tow details, counts for E. siliqua from tow videos and estimates of clam density by size groups.

Tow	Date	Time start	Duration (mins)	Depth (m)	Mid-tow Lat (dec deg)	Lon (dec deg)	Swept area (m^2)	Class1	Class2	All sizes Density (nos m^{-2})	Total	Density (nos m^{-2})	>100 mm Density (nos m^{-2})	>150 mm Density (nos m^{-2})
25	05/03/20	08:46	14:59	5.5	56.2029	-2.8985	67.2	66	6	8	77	1.1	1.1	0.7
26	05/03/20	09:11	15:00	6.0	56.2021	-2.8976	63.6	59	3	7	68	1.1	1.0	0.7
27	05/03/20	09:36	15:10	6.5	56.2012	-2.8967	67.5	59	3	11	72	1.1	0.9	0.7
28	05/03/20	10:31	15:59	8.0	56.2001	-2.9017	61.7	50	4	4	56	0.9	0.4	0.2
29	05/03/20	11:00	15:00	8.0	56.2007	-2.9029	58.2	156	16	23	187	3.2	2.4	1.2
30	05/03/20	11:35	15:13	8.0	56.2017	-2.9051	52.2	181	21	9	201	3.8	2.7	1.1
31	05/03/20	12:25	16:07	8.0	56.1984	-2.9028	61.5	225	16	12	245	4.0	2.7	1.1
32	05/03/20	13:08	14:59	8.0	56.2000	-2.9058	74.9	170	18	16	195	2.6	1.5	0.8
33	05/03/20	14:03	14:59	7.0	56.1947	-2.8950	75.4	231	17	10	250	3.3	2.6	1.8
34	05/03/20	14:31	14:59	6.5	56.1958	-2.8960	44.6	126	16	3	137	3.1	2.4	1.2
35	05/03/20	15:03	14:59	6.5	56.1969	-2.8976	70.4	251	36	35	304	4.3	3.7	2.2
36	06/03/20	08:40	11:59	7.0	56.1982	-2.9067	47.3	264	19	4	278	5.9	4.4	2.0
37	06/03/20	09:05	20:00	7.5	56.1968	-2.9056	79.0	244	26	10	267	3.4	2.5	0.8
38	06/03/20	09:33	14:59	8.0	56.1960	-2.9048	63.2	275	14	8	290	4.6	2.9	0.8
39	06/03/20	12:03	14:59	9.0	56.1998	-2.9151	59.5	346	48	16	386	6.5	5.3	2.5
40	06/03/20	12:32	14:59	9.5	56.1999	-2.9171	62.0	257	34	6	280	4.5	3.4	1.8
41	06/03/20	12:59	15:58	9.5	56.1998	-2.9192	71.2	170	8	2	176	2.5	1.3	0.4
42	06/03/20	13:54	14:59	8.5	56.1929	-2.9008	42.4	324	35	39	381	9.0	5.8	2.1
43	06/03/20	14:26	14:58	8.5	56.1931	-2.9041	73.8	365	58	24	418	5.7	4.3	2.5
44	13/03/20	09:17	14:54	7.0	56.1955	-2.9121	63.1	494	45	14	531	8.4	6.9	3.8
45	13/03/20	09:43	18:59	6.0	56.1964	-2.9107	81.0	494	60	18	542	6.7	5.7	3.4
46	13/03/20	10:15	14:59	5.5	56.1973	-2.9091	71.8	418	24	13	443	6.2	4.8	2.4
47	13/03/20	11:20	14:59	5.0	56.1946	-2.9028	74.9	354	35	15	387	5.2	3.8	1.9
48	13/03/20	11:46	14:59	5.5	56.1947	-2.9009	77.4	476	89	28	549	7.1	4.6	2.0

Table S 1: Tow details, counts for E. siliqua from tow videos and estimates of clam density by size groups.

Tow	Date	Time start	Duration (mins)	Depth (m)	Mid-tow Lat (dec deg)	Mid-tow Lon (dec deg)	Swept area (m^2)	Class1	Class2	All sizes Density (nos m^{-2})	Total	Density (nos m^{-2})	>100 mm Density (nos m^{-2})	>150 mm Density (nos m^{-2})
49	13/03/20	12:18	14:59	5.5	56.1945	-2.8980	65.8	312	27	14	340	5.2	3.8	1.7
50	13/03/20	13:25	16:56	9.5	56.1845	-2.8746	101.6	599	34	39	655	6.4	3.8	1.8
51	13/03/20	13:51	14:59	10.0	56.1835	-2.8730	60.0	476	32	43	535	8.9	5.6	2.8
52	13/03/20	14:23	14:59	11.0	56.1829	-2.8707	60.8	431	21	33	475	7.8	5.6	3.0
53	13/03/20	15:23	14:59	8.5	56.1851	-2.8706	64.0	178	22	13	202	3.2	2.9	2.4
54	13/03/20	15:50	14:59	10.0	56.1843	-2.8687	79.7	171	17	30	210	2.6	2.4	1.7
55	19/03/20	08:20	14:58	11.5	56.1887	-2.9068	89.3	234	16	26	268	3.0	1.9	0.4
56	19/03/20	08:48	15:10	12.0	56.1878	-2.9047	97.8	95	12	7	108	1.1	0.7	0.1
57	19/03/20	09:12	14:58	12.5	56.1871	-2.9028	113.3	63	4	15	80	0.7	0.5	0.2
58	19/03/20	10:19	15:00	10.5	56.1940	-2.9219	91.9	143	17	4	156	1.7	1.1	0.3
59	19/03/20	10:55	14:59	11.0	56.1961	-2.9246	94.5	163	7	7	174	1.8	0.4	0.1
60	19/03/20	11:50	15:07	12.5	56.1915	-2.9246	52.1	83	10	12	100	1.9	1.5	0.5
61	19/03/20	12:14	14:59	12.0	56.1922	-2.9252	69.1	76	8	9	89	1.3	0.8	0.2
62	19/03/20	12:44	15:05	11.0	56.1934	-2.9268	74.6	80	3	8	90	1.2	0.5	0.1
63	19/03/20	13:37	14:59	11.0	56.1916	-2.9141	124.3	223	8	20	247	2.0	1.3	0.4
64	19/03/20	14:04	14:59	10.0	56.1928	-2.9160	73.8	367	39	12	399	5.4	3.6	1.2
65	19/03/20	14:30	14:57	9.0	56.1938	-2.9302	72.2	323	21	11	345	4.8	3.1	1.1
66	20/03/20	08:18	10:59	8.0	56.1924	-2.9121	51.8	495	36	11	524	10.1	7.8	3.6
67	20/03/20	08:49	13:58	9.5	56.1916	-2.9100	76.0	666	63	8	706	9.3	7.4	3.2
68	20/03/20	09:11	15:00	10.0	56.1908	-2.9087	60.5	513	46	20	556	9.2	7.3	3.6
69	20/03/20	10:00	14:59	12.0	56.1902	-2.9219	90.0	63	3	6	71	0.8	0.5	0.1
70	20/03/20	10:23	14:59	12.0	56.1895	-2.9204	79.7	75	3	8	85	1.1	0.7	0.2
71	20/03/20	10:56	15:04	12.5	56.1889	-2.9176	83.5	58	1	17	76	0.9	0.6	0.2
72	20/03/20	11:56	15:07	12.5	56.1886	-2.9122	69.8	38	3	7	47	0.7	0.4	0.1

Table S 1: Tow details, counts for E. siliqua from tow videos and estimates of clam density by size groups.

Tow	Date	Time start	Duration (mins)	Depth (m)	Mid-tow Lat (dec deg)	Lon (dec deg)	Swept area (m^2)	Class1	Class2	All sizes Density (nos m^{-2})	Total	Density (nos m^{-2})	>100 mm Density (nos m^{-2})	>150 mm Density (nos m^{-2})
73	20/03/20	12:20	15:00	12.0	56.1881	-2.9109	52.3	43	1	11	55	1.0	0.7	0.2
74	20/03/20	12:46	14:58	13.0	56.1873	-2.9091	82.0	24	3	14	40	0.5	0.3	0.0

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References

Fahy E, Gaffney J (2001) Growth statistics of an exploited razor clam (*Ensis siliqua*) bed at Gormanstown, Co Meath, Ireland. Hydrobiolgia 465:139-151

Fox CJ (2017) To develop the methodology to undertake stock assessments on razor fish using combinations of video monitoring and electrofishing gear. Final report for Fishing Industry Science Alliance (FISA) Project 09/15. Scottish Marine and Freshwater Science 6, 8, Aberdeen, 97 pp.

Fox, C (2018) Report on razor clam surveys in the Sound of Harris and the Ayrshire coast of the Clyde (Girvan to North Bay). Scottish Marine and Freshwater Science, Vol 9 No 3, 54 pp.

Fox, CJ, McLay, A, Dickens, S (2019) Development and application of electrofishing with towed video as a new survey method for razor clams (*Ensis* spp.). Fish. Res. 214, 76-84

Hauton, C., Howell, T.R.W. Atkinson, R.J.A. Moore, P.G. (2007) Measures of hydraulic dredge efficiency and razor clam production, two aspects governing sustainability within the Scottish commercial fishery, J. Mar. Biol. Assoc. U.K. 87, 869-877.

McKay DW (1992) Report on a survey around Scotland of potentially exploitable burrowing bivalve molluscs. Fisheries Research Services Report 1/92, 70 pp.

Murray F, Copland P, Boulcott P, Rovertson M, Bailey N (2014) Electrofishing for razor clams (*Ensis siliqua* and *E. arquatus*): Effects on survival and recovery of target and non-target species. Scottish Marine and Freshwater Science Vol 5 Number 14, Marine Scotland Science, Aberdeen, 50 pp.

Scottish Government (2019) Update: Electrofishing for razor clams trial (1 February 2018 - 31 January 2019), https://www.gov.scot/publications/update-electrofishing-for-razor-clams-trial-1-february-2019---31-january-2020/. 9 pp.