Taw-Torridge
Subtidal Mussel Assessment 2020

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Contents

Version control			
Author/reviewer	**Comments**	**Date**	**Version**
J. Stewart	First draft to communicate survey outcomes	26/10/2020	0.1
J. Stewart	Formalised initial draft as full report. Reviewed by E. West.	04/11/2020	0.2
J. Stewart	Additional size frequency assessments and discussion points added.	09/11/2020	0.3
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Cover image: Satellite image of Taw-Torridge estuary (© Google).

1. Introduction

1.1 The Taw-Torridge Estuary

The Taw-Torridge estuary, the confluence of the Taw and the Torridge rivers, is located on the North Devon coast, within the North Devon Coast Area of Outstanding Natural Beauty (AONB) and the North Devon UNESCO Biosphere Reserve (Figure 1). The estuary is an important site for wildlife and has been designated as a Site of Special Scientific Interest (SSSI) (Figure 2) for over-wintering and migratory populations of wading birds, and for the rare plants found on its shores (Natural England, 1988). The estuary has a large tidal range and extensive areas of sandbanks and, particularly towards the high water mark, mudflats. These areas, along with large beaches and areas of saltmarsh, provide habitat and food sources for diverse animal species, including wading birds (Natural England, 1988). The site supports nationally important numbers of curlew, golden plover and lapwing, and other species of wader are locally abundant, including redshank, dunlin and oystercatcher (Natural England, 1988). The area supports a diverse fish community including mullet, flatfish, pollack and migratory fish species such as salmon, and is a bass nursery area (Kelley, 1986). Blue mussels, *Mytilus edulis*, are present in extensive intertidal and subtidal areas (Natural England, 1988).

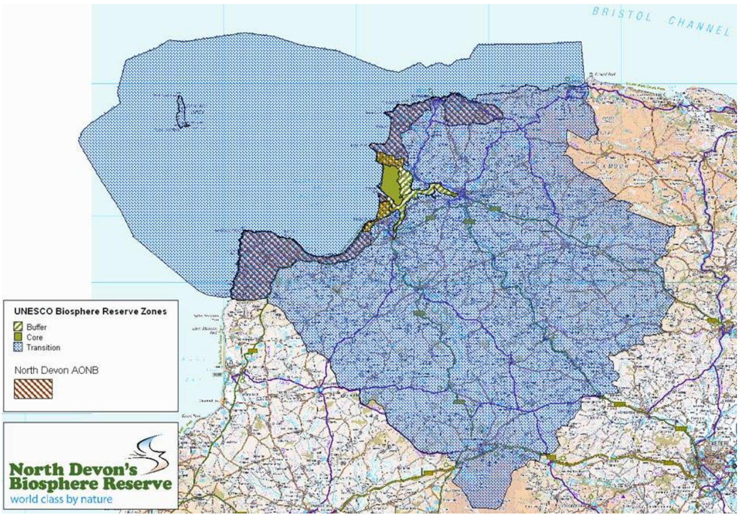

Figure 1 The location of the Taw Torridge Estuary (shown in yellow) within the North Devon Biosphere Reserve and the North Devon Coast AONB. (Taw Torridge Estuary Management Plan, 2010).

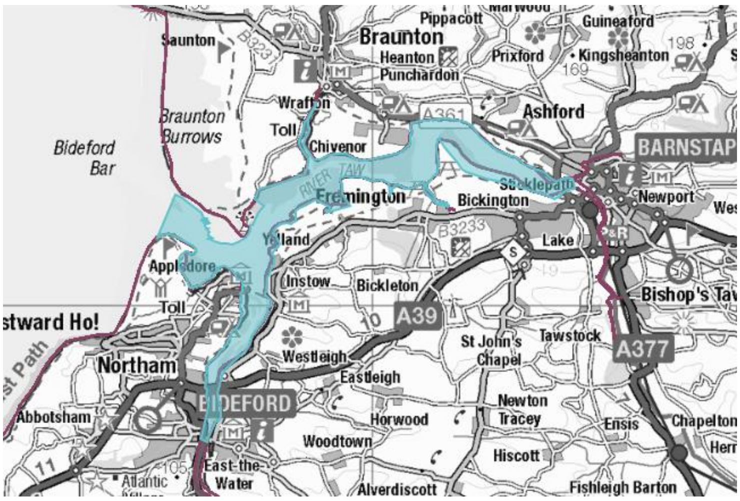

Figure 2 Taw-Torridge Estuary SSSI, shown in blue (Defra, 2016)

1.2 *Mytilus edulis*

Blue mussels, *Mytilus edulis*, are cold-water marine bivalve molluscs which can occur in brackish water (Gardner, 1996). They are found on the north Atlantic and north Pacific coast of North America, Europe and in other temperate and polar waters. Blue mussels occur at a range of shore heights from the intertidal to shallow sublittoral (Connor *et al*., 2004), and on a variety of substrates, from rocks to sediments, and in a range of conditions. “Blue mussel beds on sediment” are listed as a UK Biodiversity Action Plan (BAP) Priority Habitat (Maddock, 2008), which encompasses a range of sediments such as sand, cobbles, pebbles, muddy sand and mud. *M. edulis'* ability to occupy such a range of habitats results from its ability to withstand wide variation in salinity, desiccation, temperature and oxygen concentration (Bayne and Worrall, 1980; Seed and Suchanek, 1992; Andrews *et al*., 2011).

The reproductive strategy of *M. edulis* is to deploy a large number of gametes, approximately three million eggs, into the surrounding water where fertilisation takes place (Andrews *et al*., 2011). Following fertilisation, the planktonic larval zygotes undergo six stages of metamorphosis before settlement. Peak settlement (spatfall) occurs in the spring; newly settled postlarvae attach themselves to the substrate using byssus threads, which may be intentionally released to allow resettlement if the first settlement location proves to be unfavourable. The shell then begins to grow and, once individuals reach ~20 mm in size, they are termed ‘seed mussels’. These seed mussels are often harvested for cultivation elsewhere. The stability of the settlement and growth locations can determine the natural survival rate of seed beds (Dankers *et al.,* 2001).

M. edulis beds play an important role in the healthy functioning of marine ecosystems; having a role in coastal sediment dynamics, acting as a food source to wading birds, and providing an enhanced area of biodiversity in an otherwise sediment-dominated environment (Maddock, 2008). Subtidally, starfish, crabs, demersal fish and dog whelks predate on mussels. Predation can influence population size structure and often prevents extension of subtidal beds (Mainwaring *et al.,* 2014). Little is known about the food web in the Taw-Torridge, but predation is thought to be a key constraint on subtidal mussel populations in comparison to intertidal populations (Seed and Suchanek, 1992); Holt *et al.* (1998) highlight that starfish populations destroy most sublittoral mussel settlements in The Wash each year, and also attack cultivated plots at or below mean low water springs. Mussel beds support their own diverse communities as the mussel matrix, composed of interconnected mussels and accumulated sediments and debris, provides numerous microhabitats and an organically enriched environment (Andrews *et al*., 2011; Seed and Suchanek, 1992). Blue mussels are filter feeders, feeding primarily on micro-algae, suspended debris and zooplankton, and play a vital role in estuaries by removing bacteria and toxins.

Current threats to *M. edulis* beds include: commercial fishing, water quality, anchoring, and, particularly for intertidal beds: bait digging, coastal developments and intensive recreational hand gathering (Maddock, 2008). Poor spat settlement combined with a severe winter and storms 2014 are thought to have contributed to a decline in intertidal mussels stocks in the Taw-Torridge system in 2014. Following this decline, and an increase in interest from numerous commercial harvesters, Natural England, working with D&S IFCA, introduced management measures to ensure that enough mussels would be available to provide an adequate food supply for the birds for which the SSSI is designated. No more than 500kg of mussels can be removed from the SSSI per month, and any business wishing to remove mussels must notify Natural England and D&S IFCA of their intentions to do so by 23rd of the month prior to the month when mussel harvesting is proposed. This allows Natural England and D&S IFCA to determine if the planned removal will, in combination with other planned activities, be likely to result in the 500kg limit being exceeded. If this is the case, planned removal by all individuals will need to be reduced accordingly. Records of the amount of mussels removed (including location) together with copies of movement documents are submitted to Natural England and the IFCA within 14 days of harvesting.

The changing and variable nature of the hydrological environment can also pose a threat to some mussel populations; for example, in the Taw-Torridge area, there is some local concern that subtidal mussel beds may be prone to scouring and disintegration overwinter, particularly during periods in which the strong local tidal movements coincide with high freshwater input and riverine flows. Mussels show preferential settlement and growth in areas of high flow, for example in the mouths of estuaries. However, extreme high flows can depress feeding and growth rates, and cause mussels to become detached from the substrate (Dare, 1976; Jenner *et al.,* 1998; Widdows *et al.,* 2002). The impact of increased flow rates depends on the local context, including the composition of the underlying substrate, the density of the mussel bed, the typical average flow rate, and the magnitude of the increase in flow rate (Mainwaring *et al.,* 2014).

Mussel resilience to increases in flow rate depends in large part on the strength of the byssal attachment to the substrate, which in turn can adapt according to local conditions. The strength and number of byssal thread attachments produced by *M. edulis* and related species is higher in areas that typically experience higher flow rates (Young, 1985; Dolmer and Svane, 1994; Alfaro, 2006). The strength and number of byssal thread attachments also increases in individual mussels over short time periods, allowing further adaptation to gradual increases in flow rate: Young (1985) observed 25% strengthening of attachments within eight hours of increased water agitation associated with a storm commencing. However, sudden increases in water movement do not allow time for such adaptation, and mussels are susceptible to being swept away (Young, 1985).

The composition of the underlying substrate also affects mussel vulnerability to high water flow; individuals attached to rock are typically more resistant to removal than those attached to loose boulders, cobbles or sediment. Increases in flow have the potential to resuspend and remove finer sediments from the estuary bed (Tyler-Walters, 2008; Mainwaring *et al.,* 2014), and the rate of removal depends in part on the density of the mussel bed. For example, in flume tank studies, Widdows *et al.* (2002) showed that increased water turbulence and scouring around live mussels caused rates of resuspension of sandy sediment that were four and five times higher, respectively, on areas with 25% and 50% mussel cover compared to bare sediment. However, areas with 100% mussel cover remained more stable, with three times lower resuspension rates than bare sediment. On mixed sediment or cohesive mud substrata, increasing mussel density was typically associated with higher stability and lower risk of mussel removal by high water flows (Widdows *et al.*, 2002). However, these flume tank studies used a maximum flow rate of 0.45 m/sec, which is lower than that experienced at peak flow in the Taw-Torridge estuary; it is therefore unclear how these results translate to the local subtidal mussels at this location.

1.3 Objectives

The objective of this project was to conduct a broad-scale grab survey of the subtidal areas of the Taw-Torridge Estuary, to define where the mussel beds are, in conjunction with information shared by a local fisherman. Results of these surveys will help to inform future management of the mussel beds on the Taw-Torridge, and the development of shellfisheries in this part of the D&S IFCA's District.

2. Methodology

This survey was conducted by a D&S IFCA officer and two fishermen who were local to the Taw Torridge, on board an 8.3 m multi-use fishing vessel. Prior to the survey, the lead fisher was provided with UKHO charts on which he indicated the presence of subtidal mussel beds, based on his local knowledge. These annotated charts were georeferenced within a Geographic Information System (QGIS) and used to generate a grid of 38 sample stations covering primary areas of interest between the estuary mouth and a line joining the Crow Point and Coolstone areas (Figure 3). These sample locations focused on areas in or near to areas that the fisher had identified as subtidal mussel beds, in order to ground-truth the local knowledge and gain an estimate of mussel density where possible. The points shown on Figure 3 were manually transferred to the on-board chart plotter, and located *in situ* during the survey, starting with the western-most sampling station (station 1). The survey was conducted over the high water period between approximately 09:20 – 13:00 on 23rd October 2020 (HW 5.83m at 11:14AM).

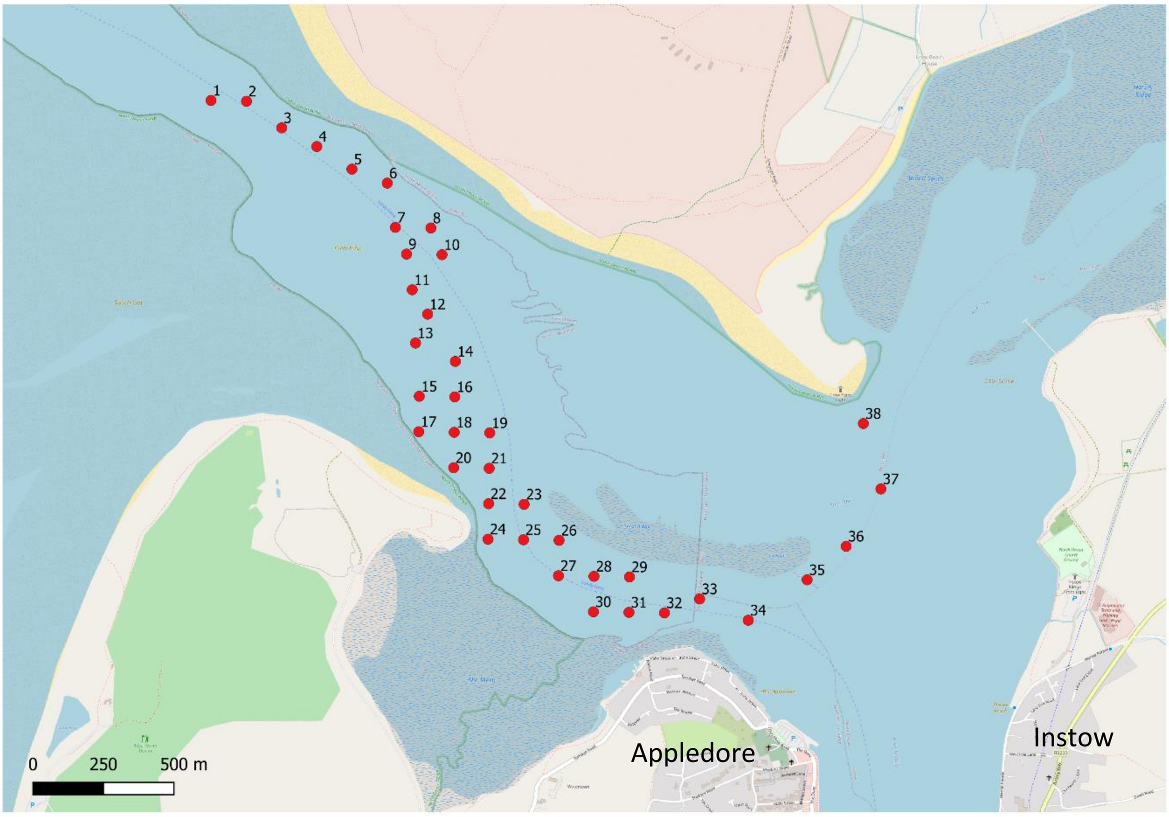

Figure 3. Target sample stations for survey on 23rd October 2020, on an OpenStreetMap base map.

A 10kg Van Veen grab was deployed three times at each station, and hauled by hand on each occasion. The second and third grabs at each station were typically within 10 m of the initial grab. The estimated time-per-grab used in planning the survey allowed for only a single grab at each of the 38 sample stations; however, the process was quicker than anticipated, allowing for a larger number of grabs over a shorter sampling period (one high tide window, rather than three). The increased number of grab attempts was deemed necessary due to grab failures and a need to increase replication where possible.

During sampling, the latitude and longitude of the grab points were recorded, along with the success of the grab (whether it was full of substrate) and the presence/absence of mussel. Grabs containing mussel were stored in individually-labelled polythene bags for later measurement. In total, 114 grab attempts were made. Of these, 40 grabs were completely successful (closed fully and were brought up full). Mussel was present in 53 grabs: present in 20/40 successful grabs and 33/74 unsuccessful grabs. Therefore, mussel presence was indicated even in some 'unsuccessful' grabs. The same hauling technique and timing was used for each grab, which is unlikely to have contributed to the success or failure of each grab.

For each grab containing mussel, the length of all mussels were measured and divided into the following size groups; 1-10mm, 11-20mm, 21-30mm, 31-40mm, 41-50mm, 51-60mm, 61-70mm, 70+mm, and the weight of each size class was recorded to the nearest gram. Length distributions were plotted as histograms and as empirical cumulative distribution functions (ECDFs), and were compared to the length distributions of mussel found at intertidal beds surveyed by D&S IFCA in 2020. Figure 4 shows the locations and names of these intertidal beds. These beds were surveyed using the Dutch wand method over transects walked across the beds. In summary, transects were walked in a zig-zag pattern across the intertidal beds. The start and end coordinates of each transect were recorded using a handheld GPS. A 4'ft bamboo cane with an 11cm ring attached to the end, arranged so that the ring sits flat on the ground when held out to one side, was used to determine the mussel coverage for each transect. Every three paces along each transect the cane was flicked out to one side and it was recorded whether it was a "hit" if the ring contained live mussels, or a "miss" if the ring did not contain live mussels. On every fifth hit the contents of the ring were taken as a sample, using an 11cm diameter corer. All mussels from each transect were measured to the nearest mm. Full methods and results of these surveys are available in an upcoming intertidal mussel stock assessment report; reports from previous years are available here.

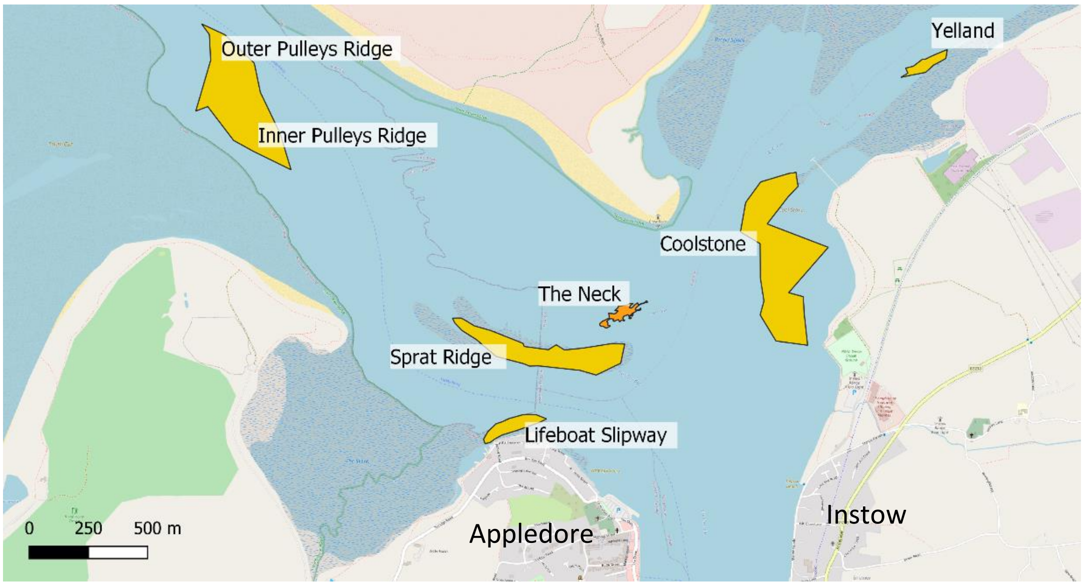

Figure 4. Locations and names of intertidal mussel beds (yellow polygons) surveyed by D&S IFCA in the Taw-Torridge.

3. Results

The conditions of tide, wind and swell were particularly challenging on occasion, and these appear likely to have been the primary determinants of grab success/ failure. On many occasions, a failed grab also did not close properly e.g. due to a stone or mussel in the mouth of the grab preventing closure. Speculatively, experience suggests that a heavier grab may be beneficial for future work, though the fisher has indicated that these beds may be best sampled by hand on a low spring tide (particularly between Pulleys and Sprat Ridge).

Figures 5 – 7 show the recorded locations of each grab sample, moving downstream in the estuary. The stations sampled correspond well with those planned (Figure 3), with the exception of a small number of stations near the estuary mouth, around the 'Mid Ridge' area. This is likely due to error in transferring stations to the vessel's chart plotter. However, the stations entered into the chart plotter were also based on the fisher's local knowledge of the geography and mussel distribution, and the fisher indicated that the stations entered into the chart plotter were representative of the areas to be sampled. Figures 5 and 6 appear to show sample stations on the intertidal area of Outer Pulleys. However, closer inspection of D&S IFCA intertidal survey data and cross-referencing with UKHO charts has shown that these do appear to be subtidal areas outside of the areas sampled during D&S IFCA's intertidal surveys (Thomas, 2019).

On Figures 5 – 7, diamond-shaped markers indicate 'successful' grabs (those that came up full), while unsuccessful grabs are depicted by small circular markers. Green markers of either shape indicate that mussel was present in the grab, while black markers indicate mussel absence. Black circular markers cannot be taken as evidence of mussel absence, due to grab failure. Black diamond markers indicate mussel absence in the area sampled by the van Veen grab (0.028m^2).

Overall, the area between Sprat Ridge and Pulleys (west of the red line in Figure 5) had a high proportion of mussel presence in grabs: 71% of successful grabs and 55% of unsuccessful grabs in this area contained mussel. This included musel presence in an area identified by the fisherman as containing mussel spat/seed (survey stations 18 – 21), though the majority of the mussels in this area were larger than 40 mm in length, as opposed to the smaller sizes expected in an area of seed mussel. Areas to the south of Sprat Ridge (south of the red line in Figure 6), had a lower proportion of mussel presence overall: 36% of successful grabs and 17% of unsuccessful grabs contained mussel; the proportion of mussel presence was the same for the subtidal bed nearest to the lifeboat mooring in this area, directly south of Sprat Ridge. Anecdotal evidence has highlighted an area of subtidal mussel between Sprat Ridge and Crow Point; this is near to and overlapping with the area of possible spat/ seed mussel identified by the fisherman in this area, and shown by the blue hatching in Figure 7. However, the extent of this subtidal resource is unclear and unquantified. Three successful grabs near this area confirmed mussel presence (Figure 7) but grabs further north, towards Crow Point and Coolstone, failed to find evidence of subtidal mussel. Figure 8 shows the mussel count within each successful grab sample (mussels per 0.028m^2). Highest mussel densities in successful grabs appear to occur in the area between Outer Pulleys and the lifeboat area (Figure 8).

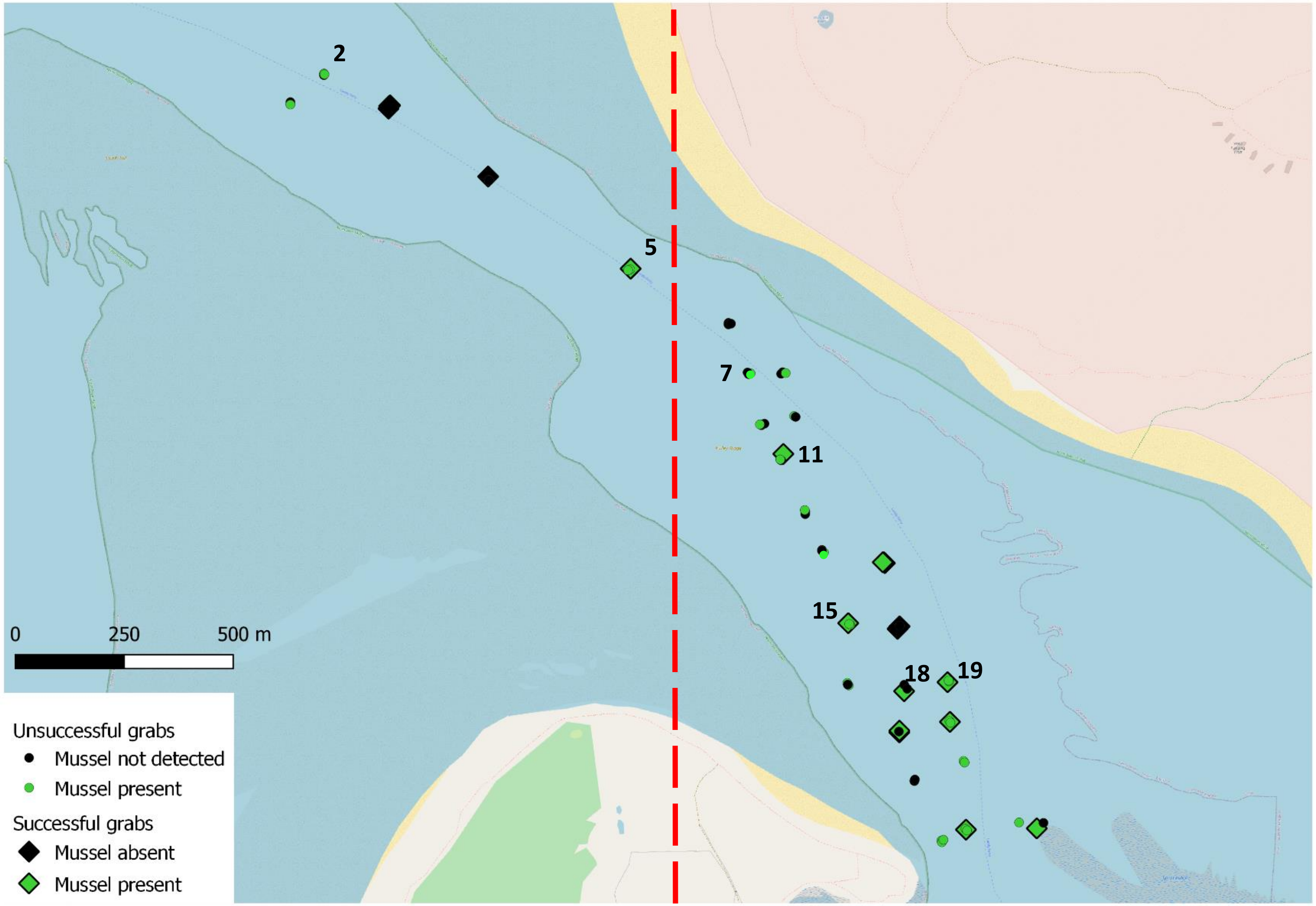

Figure 5. Western-most sampling stations surveyed on 23/10/2020. Sample points that are depicted here on the Outer Pulley ridge area appear to be subtidal, and just east of D&S IFCA's intertidal survey areas. Successful grabs are depicted by diamond markers, unsuccessful grabs by circle markers. Green markers indicate mussel presence, black markers indicate mussel absence, with the caveat that absence of mussel in unsuccessful grabs cannot be taken to indicate mussel absence with any certainty.

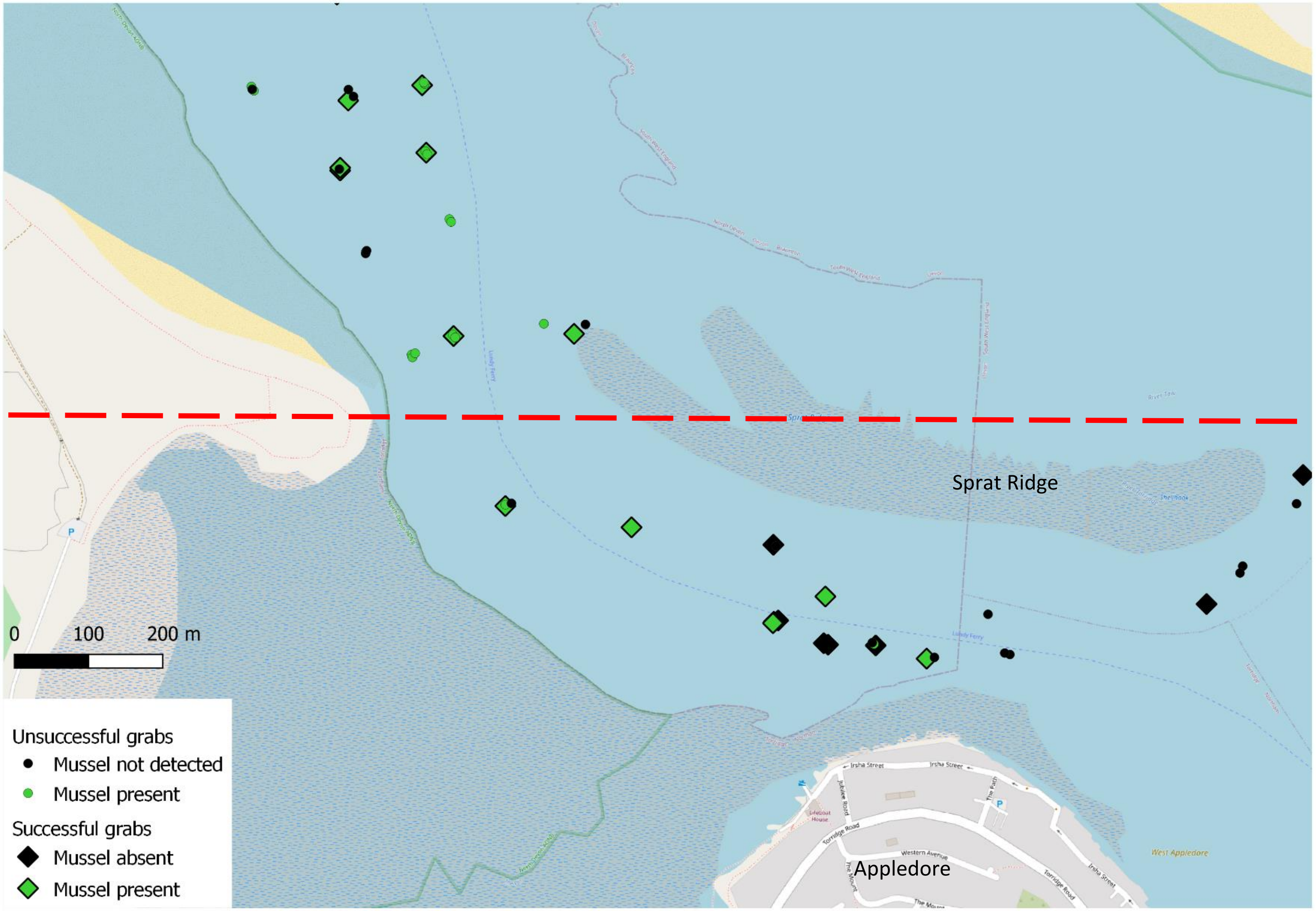

Figure 6. Sampling stations in the vicinity of ‘the cannons’ and Pulleys area, surveyed on 23/10/2020. Successful grabs are depicted by diamond markers, unsuccessful grabs by circle markers. Green markers indicate mussel presence, black markers indicate mussel absence, with the caveat that absence of mussel in unsuccessful grabs cannot be taken to indicate mussel absence with any certainty.

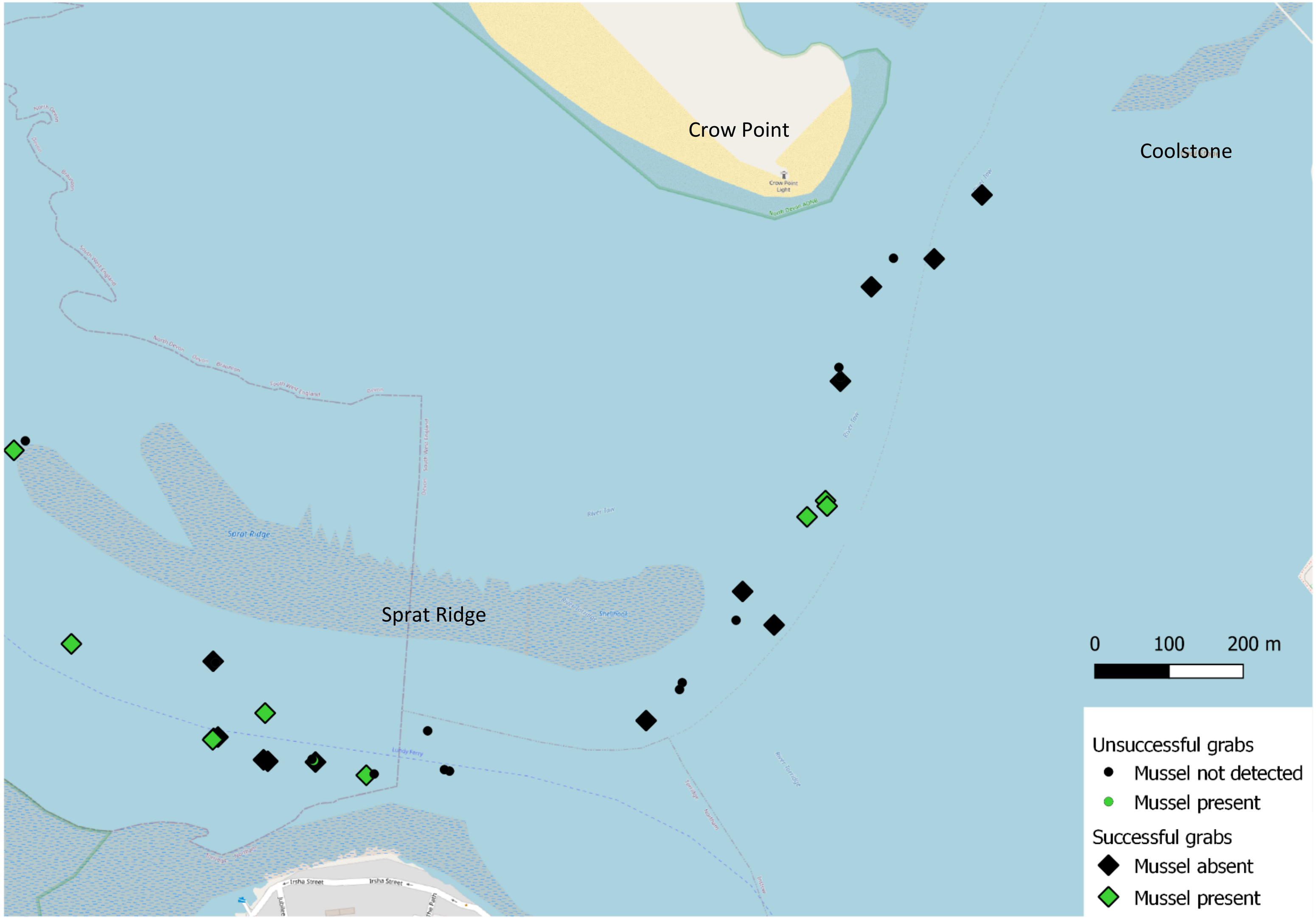

Figure 7. Eastern-most sampling stations surveyed on 23/10/2020. Successful grabs are depicted by diamond markers, unsuccessful grabs by circle markers. Green markers indicate mussel presence, black markers indicate mussel absence, with the caveat that absence of mussel in unsuccessful grabs cannot be taken to indicate mussel absence with any certainty.

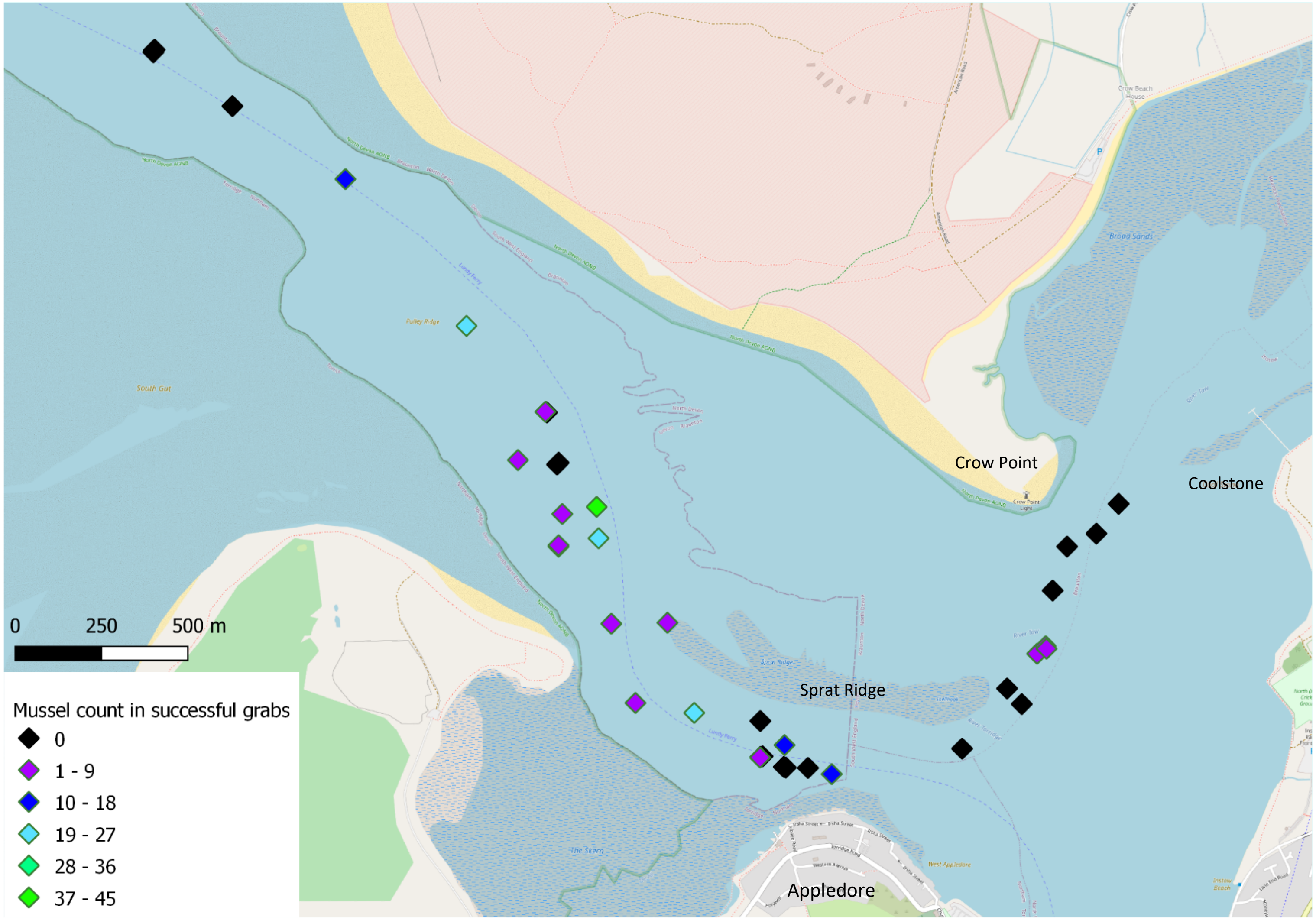

Figure 8. Count of mussels in each successful grab (mussels per $0.028m^2$). Mussels were present in 20 out of 40 successful grab samples.

The size frequency distribution of mussels observed from all grab samples on 23/10/2020 (Figure 9) is indicative of at least two age classes: there is a bimodal (two-peaked) distribution of mussel lengths, with peaks at ~ 20mm and ~42 mm (Figure 9). Mussels in the smaller size classes were typically found towards the mouth of the estuary: with the exception of three mussels found at station 11, the smallest 44 mussels were found at stations 2 and 5 (numbered on Figure 5). All mussels below 30 mm in length were found in stations seaward of Sprat Ridge, and were detected at stations 2, 5, 11, 15 and 19 (numbered on Figure 5). However, it should be noted that some of the seaward stations also contained some of the largest mussels: 31% of mussels 50 mm or larger were found at stations 7, 11, 18 and 19 (numbered on Figure 5).

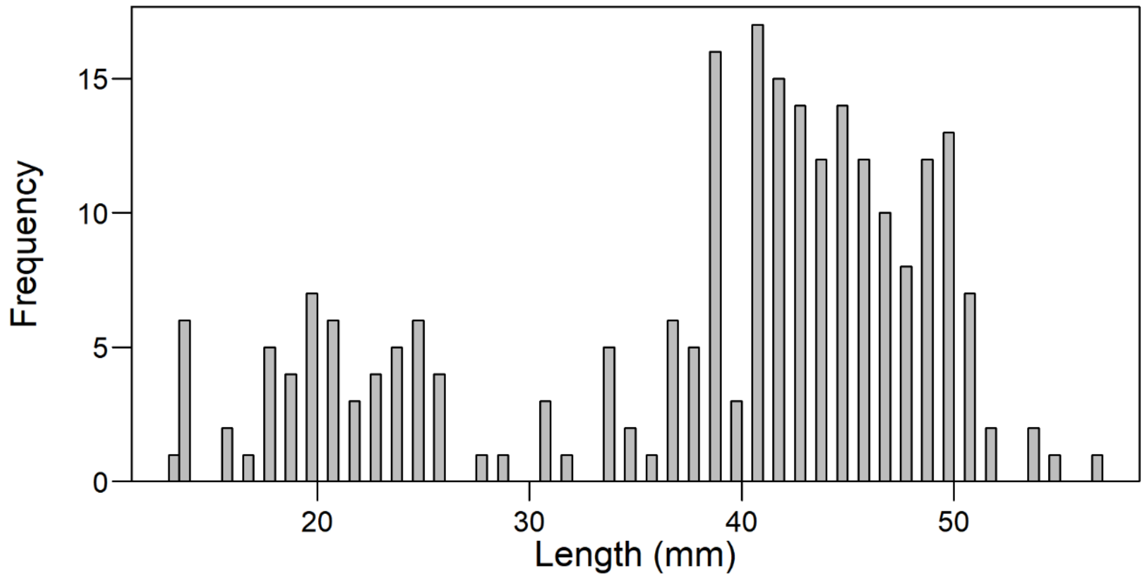

Figure 9. Size distribution of mussels retrieved in grab samples taken from subtidal areas of the Taw Torridge estuary on 23/10/2020.

The distribution of different mussel lengths among different geographic areas is shown clearly in Figure 10. Figure 10 shows 'empirical cumulative distribution functions' (ECDFs), showing the cumulative proportion of mussels of each length found in particular geographic regions. The proportion of smaller mussels was much higher at stations near to the estuary mouth (estuary mouth to outer Pulleys, stations 1 – 10) than in the region from innner Pulleys to Sprat Ridge (stations 11 – 23) or from Lifeboat to Coolstone (stations 24 – 37). Indeed, 80% of mussel found in the mouth area (stations 1 – 10) were smaller than 30 mm long (figure 10). Mussel found at stations in the inner Pulleys to Sprat Ridge area were generally larger (mostly > 40 mm, some 30 – 40 mm), and those in the Lifeboat to Coolstone area were all longer than 40 mm (Figure 10).

Figure 11 overlays Figure 10 with the ECDFs for length of mussels found in intertidal areas surveyed by D&S IFCA during 2020. The mussels found at the intertidal Pulleys bed were clearly smaller than in other intertidal beds, and of similar lengths to many of those found in subtidal areas in the estuary mouth (shown by initial overlap of left-most blue and black lines on Figure 11). The other intertidal beds typically had a much higher proportion of longer mussels; the intertidal beds at Coolstone and The Neck had the highest proportions of larger mussels compared to smaller mussels (Figure 11). Of the successful grab attemps, station 11 is notable for being the only set of grabs that contained a clearly bimodal distirbution of mussel lengths, indicating multiple age classes (Figure 12); however, it should be noted that sample sizes were small in most grabs, so it is possible that multiple age classes coexist in other locations.

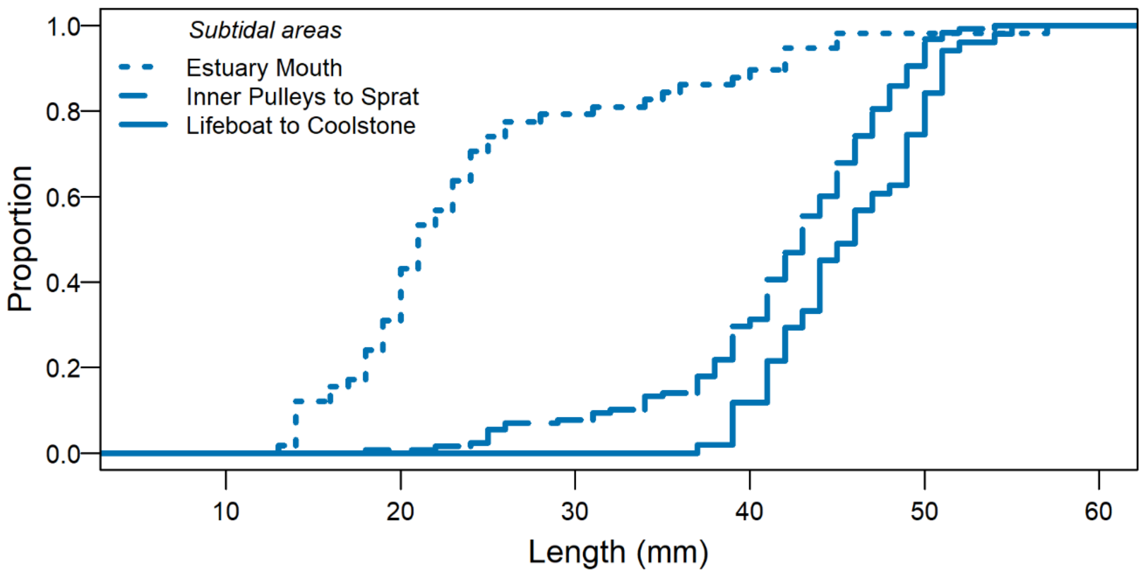

Figure 10. Empirical cumulative distribution function for subtidal areas of mussel, showing the proportion of mussels in each length category (mm) in each of three subtidal areas: Estuary Mouth (mouth to Outer Pulleys; stations 1 – 10), Inner Pulleys to west of Sprat Ridge (stations 11 – 23) and Lifeboat to Coolstone (stations 24 – 37).

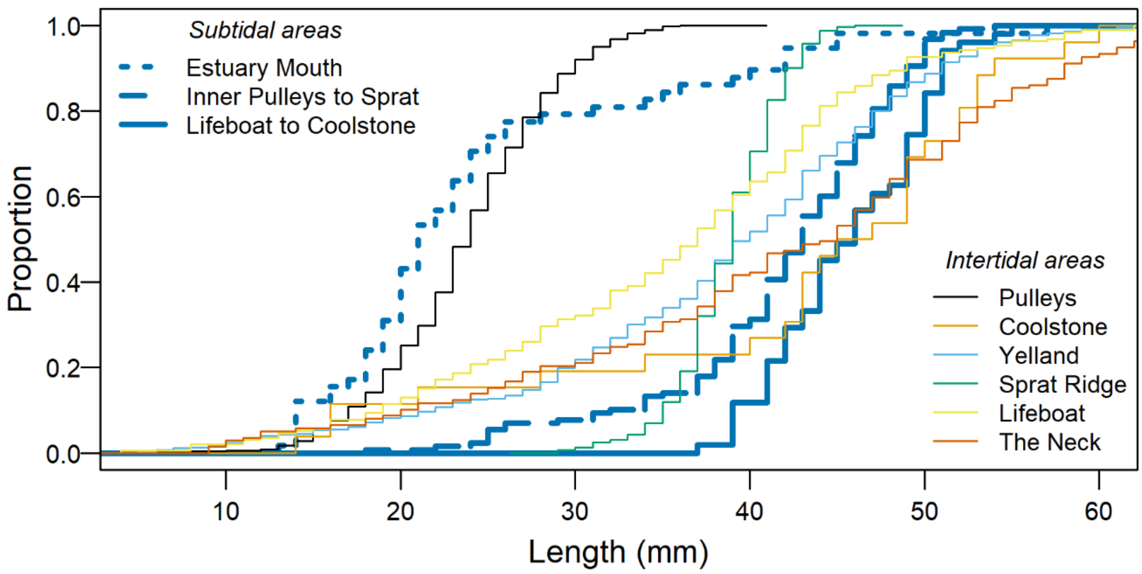

Figure 11. Empirical cumulative distribution function for subtidal and intertidal areas of mussel, showing the proportion of mussels in each length category (mm) in each of three subtidal areas (Estuary Mouth to Outer Pulleys: stations 1 – 10; Inner Pulleys to west of Sprat Ridge: stations 11 – 23; Lifeboat to Coolstone: stations 24 – 37) and six intertidal beds.

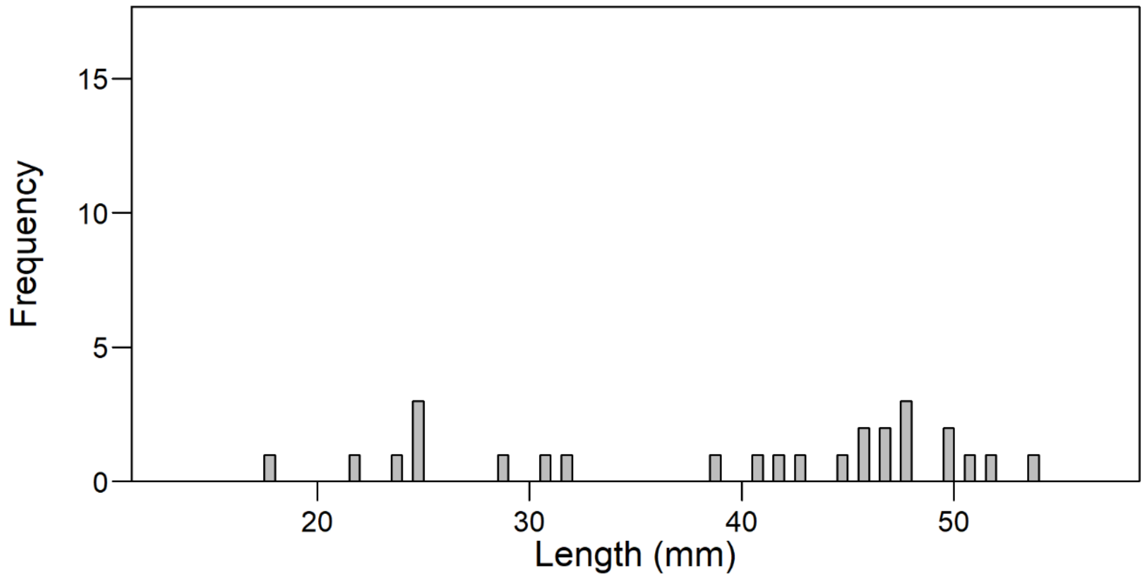

Figure 12. Size distribution of mussels retrieved in grab samples taken from station 11 on 23/10/2020. Graph axes match those of Figure 9 for comparative purposes.

4. Discussion

The conditions of tide, wind and swell were particularly challenging, particularly during early stages of this survey, and these appear likely to have been the primary determinants of grab success/ failure. On many occasions, a grab failed due to, for example, a stone or mussel in the mouth of the grab preventing closure. The relatively low success rate of the grab limits the inference that can be made regarding subtidal mussel distribution and density. Despite this, the survey was valuable in ground-truthing local fisher knowledge of subtidal mussel distribution in most beds identified (Figures 5 – 7), and has expanded D&S IFCA's understanding of the subtidal mussel resource.

In particular, the area between Sprat Ridge and Pulleys had a high proportion of mussel presence in grabs, regardless of grab success or failure; this is in line with the fisher's expectations of mussel bed presence in this area (Figure 5). Additionally, this area appears to return relatively high densities of mussel in successful grabs (Figure 8). However in other areas, such as that near the lifeboat mooring south of Sprat Ridge, a higher proportion of successful grabs indicated mussel absence, despite fisher expectations of mussel bed presence (Figure 6). In this area, and in potential beds in upstream areas towards Coolstone (Figures 6 and 7), there were successful grabs that indicated mussel presence in close proximity to successful grabs in which mussels were absent; this pattern suggests relatively fine-scale patchiness in subtidal mussel distribution in these areas.

The fisher indicated an expectation of more mussel in the area upstream of Sprat Ridge, towards Coolstone and Crow Point; absence of mussel here may be related to grab failure, though successful grabs in this area also showed a high proportion of mussel absence. This may be related to a potential influx of sand from the dunes north of Crow Point, which may have smothered the mussel. However, the likelihood and extent of this is unclear; this inference is based on the fisher's local knowledge, but is supported by the presence of fine sediment in successful grabs retrieved from this area. Elsewhere, shifting sands have been seen to limit the range of *M. edulis* through burial and abrasion (Daly and Mathieson, 1977).

There is known to be an area of intertidal mussel in ‘the neck’ (between Sprat Ridge and Crow Point) which has been surveyed by D&S IFCA’s officers during 2020. This area is surrounded by subtidal mussels which were visible during the intertidal survey. However, the extent of this subtidal resource is unclear, and was not sampled during this survey.

Mytilus edulis growth rates vary by location depending on, for example, water quality, temperature, water flow and food availability, but average growth rates of approximately 10mm per annum may be expected for southern England (Bayne and Worrall, 1980, Handå *et al*., 2011). The observed distribution of mussel lengths is therefore indicative of the presence of at least two distinct age classes, which appear to coexist only rarely: only station 11 had a clearly bimodal distribution of mussel lengths. Smaller size classes were more common in downstream areas towards the estuary mouth and west of Sprat Ridge, suggesting higher abundance of smaller (<30 mm) seed mussel in these potential beds, relative to more upstream areas. Indeed, Figures 10 and 11 suggest that both intertidal and subtidal areas near the estuary mouth have higher abundances of smaller mussel than the upstream areas. Intertidally, Pulley’s ridge appears to only contain smaller mussel, perhaps of a single age class, while the nearby subtidal resource has more size diversity and may consist of two age classes (though the limited data presented here suggest that these distinct age classes rarely coexist in small areas).

Small mussel were absent from grabs obtained from subtidal areas upstream from the outer Pulley’s area towards Coolstone, suggesting the existence of a single older age class in this area. Broadly, the intertidal beds appear to support more diverse size classes than the subtidal areas, as reflected in Figure 11. Though it is not possible to draw substantial quantitative inferences from the data presented here, these results support previous observations of preferential mussel settlement and growth in areas of high flow, for example in the mouths of estuaries (Mainwaring *et al*., 2014). However, extreme high flows can depress feeding and growth rates, and cause mussels to become detached from the substrate (Dare, 1976; Jenner *et al.,* 1998; Widdows *et al.,* 2002).

The impact of increased water flows resulting from higher freshwater inputs during autumn/winter storms has become a local concern in the Taw-Torridge estuary. As highlighted in Section 1.2, the impact of increased water flow rates on subtidal mussel populations depends on the local context, including the composition of the underlying substrate, the density and strength of the mussels and their byssal attachments, and specifics of the hydrological regime (including the typical average flow rate and the magnitude of the increase in flow rate) (Mainwaring *et al.,* 2014). The present survey has ground-truthed mussel presence in some subtidal areas, but was not suited to accurately describing fine-scale mussel distribution and density patterns, or assessing the underlying sediment or hydrological regime to evaluate risk of mussel detachment during periods of high flow. The fishers involved in the survey indicated that an alternative sampling method for these beds may be hand sampling from a shallow-draft boat on a low spring tide (particularly between Pulleys and Sprat Ridge). Depending on the resolution of the associated sampling grid, this approach may allow a more quantitative evaluation of local mussel distribution and density. Alternative methods also include assessment of distribution using side scan sonar, ground-truthed by intensive grab sampling, perhaps with a heavier grab type, either at high tide (neaps) or low tide (springs). Holt *et al.* (1998) highlighted that monitoring of changes in the extent of sublittoral biogenic reef communities will require acoustic methods in many cases, particularly where they are deep and extensive, but that such methods will always require groundtruthing effort.

Mussel detachment due to high flow rates may be more likely in the subtidal than intertidal due to constant exposure to this pressure and high water flow rates in the main channel, but intertidal mussel are also at risk of detachment due to the 'to and fro' of wave movement on shores – particularly shores of higher wave exposure (Tyler-Walters, 2016). The depth of subtidal mussel beds provides some protection from this motion, and a degree of wave exposure may be beneficial to subtidal mussels: Westerbom and Jattu (2006) found that mussel densities in subtidal beds typically increased with increasing wave exposure, though the highest biomass was found in areas of intermediate exposure, potentially due to the removal of larger mussels at high wave exposure levels. Less exposed areas may suffer from higher sedimentation, which could stifle recruitment, increase early post-recruitment mortality, or smother young adult mussels (Westerbom and Jattu, 2006). In rocky habitats, increased wave exposure can allow mussels to dominate the ecological community and form beds. However, beds are more susceptible to damage from increased wave exposure if they are patchy or found on finer sediment substrata, which are more typical of wave-sheltered environments (Seed and Suchanek, 1992; Brosnan and Crumrine, 1994). In these sedimentary, wave sheltered habitats, the build-up of mussel muds (silt, faeces and psuedofaeces) may reduce overall attachment of the bed to the substratum, increasing its susceptibility to wave action (Seed and Suchanek, 1992).

Fishing activities that target mussel generally have the potential to directly impact upon subtidal and intertidal mussel populations, which have low resistance to this pressure (Mainwaring *et al.,* 2014). Mussel removal, whether by hand or by dredge, can cause significant damage to beds, including widespread loss of mussel and associated biodiversity (Holt *et al*., 1998; Smith and Murray, 2005; Mainwaring *et al.,* 2014). Low-level disturbance of *Mytilus californianus* caused a substantial decline in bed mussel density, abundance and biomass, mostly due to loss of additional mussels resulting from weakening of byssal attachments between remaining mussels (Smith and Murray, 2005). In a small-scale study of trampling effects on intertidal mussel beds, trampling caused substantial mussel dislodgement, particularly in areas with less dense mussel aggregations, and patches of bare space resulting from mussel loss continued to expand due to wave action even a year after the trampling disturbance had ceased (Brosnan and Crumrine, 1994).

In the UK, dredging for mussel occurs on subtidal and intertidal soft sediment, but the majority of commercially-harvested mussel beds are regularly replenished with seed, so the recovery of local mussel populations from dredging activity should be rapid in maintained beds (Mainwaring *et al.,* 2014). However, in natural (wild) beds, the recovery could be significantly longer due to sporadic recruitment and indirect effects from water movement (Paine and Levin, 1981; Seed and Suchanek, 1992; Mainwaring *et al.,* 2014). Mussel beds on harder substrates are less likely to be affected by dredges and are therefore more vulnerable in the intertidal areas where they are targeted by hand-gatherers (Mainwaring *et al.,* 2014). Across substrate types, dense, multi-layered mussel beds are thought to be more resistant to the effects of gaps in the bed and to small-scale gathering activities, provided that damage to the upper layers does not affect deeper layers and the attachment to the substrate is maintained (Brosnan and Crumrine, 1994). A further concern regarding fishing activities is that damage to the bed attracts mobile scavengers and predators to feed on exposed, dead and damaged individuals (Kaiser and Spencer, 1994; Ramsay *et al*., 1998;

Groenewold and Fonds, 2000; Bergmann *et al*., 2002), and may thereby increase predation pressure on surviving *M. edulis*. Additionally, mussel dredging temporarily increases the resuspension of sediments, which may smother remaining mussels (Riemann and Hoffmann, 1991). The direct impacts of hydraulic dredging are less clear, but may be less long-lived (Mainwaring *et al.,* 2014).

When damaged patches occur in mussel beds, driven by fishing pressure or natural events (e.g. impacts of natural flotsam), recovery can occur following good recruitment (Tyler-Walters, 2008). However, even in sheltered areas, recovery of mussel beds may be impeded by limited larval supply (Mainwaring *et al.,* 2014). In the Taw-Torridge, and more widely, the source areas for recruitment, and the relationship between local stock and recruitment, are poorly understood (Seed and Suchanek, 1992; Holt *et al.,* 1998). In addition, the damaged patch may expand through weakening of the byssal attachments of remaining mussels, leaving the remaining mussels more vulnerable to erosion from storm damage (Denny, 1987) or high water flow associated with wetter weather, particularly in autumn/winter. This erosion and removal of the bed may occur despite periods of good recruitment (Mainwaring *et al.,* 2014), and mussel losses caused by indirect effects following fishing can be substantially greater than the direct effects of fishing (Herlyn and Millat, 2000). Indeed, the principles and management measured outlined by Eastern Sea Fisheries Joint Committee (ESFJC, 2008) highlighted that, in The Wash, "once a sublittoral mussel bed has been disturbed, it is quickly lost through predation and scouring". However, ESFJC allowed the fishing of up to 80% of the identified sublittoral beds, with no restrictions on days at sea based on the assertion that "the ephemeral nature of sublittoral mussel beds means that unless the stocks are harvested they are very likely to be lost to natural predation or physical scouring. The overall quota allows the majority of the resource to be transferred onto intertidal areas for cultivation and future harvesting. Leaving a proportion of sublittoral mussel stocks *in situ* ensures that this food source for natural predators is not completely removed from its settlement location" (ESFJC, 2008). These assertions regarding the ephemeral and sensitive nature of sublittoral mussel stocks are supported by recent experiences in the Wash (R. Jessop, Eastern IFCA, *pers. comm.*).

The uncertainties regarding pressures and threats to local subtidal and intertidal mussel populations should be considered during assessment of any proposed management activities that seek to reseed intertidal areas, or otherwise transport mussel between subtidal and intertidal areas.

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