Stock Assessment of the Edible Mussel (*Mytilus edulis*) Beds on Fenham Flats 2020

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Abstract
The purpose of this report is to assess and continue to monitor the state of the mussel bed on Fenham Flats, Lindisfarne National Nature Reserve (NNR). The perimeter of the mussel bed was mapped, and percentage cover of mussels was estimated using the 'Walker and Nicholson' technique. Biomass, density and total number of mussels at the site were also calculated. Samples of mussels were collected, and total shell length and weight were measured.

The mussel bed on Fenham Flats in 2020 covered an area of 52.66ha with a percentage cover of 42.9%. The estimated values obtained for density, biomass and total number of mussels have decreased compared to the 2019 survey. Mean length of mussels sampled in 2020 increased from those sampled in 2019. The length distribution was typically unimodal and skewed towards a larger mussel size, with 96% of mussels were larger than the recommended minimum size of 45mm, shifting from a bimodal distribution observed in previous years.

This report is intended to provide information relating to the health and distribution of the mussel bed on Fenham Flats in order to inform future management of the site.

Introduction
The edible mussel (*Mytilus edulis*) is widely distributed, occurring in boreal and temperate waters, in both the southern and northern hemispheres (OSPAR, 2010). *M. edulis* is tolerant of a wide range of environmental conditions (Fisheries Agriculture Organisation (USA) no date) including fluctuations in salinity (Andrews *et al.,* 2011), and therefore occurs in both marine and brackish waters (Gardner, 1996). Mussels can form dense beds (Fenton, 1978) using byssus threads to attach to the substratum (Babarro *et al.,* 2008) and can be considered a biogenic reef.

M. edulis beds are included in the OSPAR (Annex V) list of threatened and declining species and habitats and are listed as a UK biodiversity action Plan (BAP) Priority Habitat (Maddock, 2008). Threats to mussel beds include, but are not limited to, bait collection (Maddock, 2008), gathering for human consumption (Fenton, 1978), pollution (Hilgerloh, 1997), coastal development and anchoring (Maddock, 2008). As threatened and declining species is currently unknown whether mussel beds are declining because of the aforementioned threats, due to bird predation or a combination of factors (Hilgerloh, 1997).

In 2005, the Northumberland Sea Fisheries Committee (NSFC) (now Northumberland Inshore Fisheries and Conservation Authority (NIFCA)) was approached by Natural England who requested that NSFC conduct a stock assessment survey of the mussel beds at Fenham Flats, Lindisfarne in order to consider reopening the mussel beds to commercial harvesting within the Lindisfarne National Nature Reserve. NIFCA has continued to carry out annual stock assessment surveys at the site, providing an annual and unique long-term record of the population dynamics of the mussel bed. The same method has been used since inception to facilitate comparisons over time.

Methods
A series of surveys have been conducted on the mussel bed at Fenham Flats annually since March 2005. The 2020 survey was conducted at low water on a spring tide on the 11th March by NIFCA staff and volunteers from Natural England.

Study Site
The study site is located on the mussel bed at Fenham Flats, Lindisfarne on the extensive mudflats south of Holy Island, located within the Lindisfarne National Nature Reserve (NNR) (Figure 1).

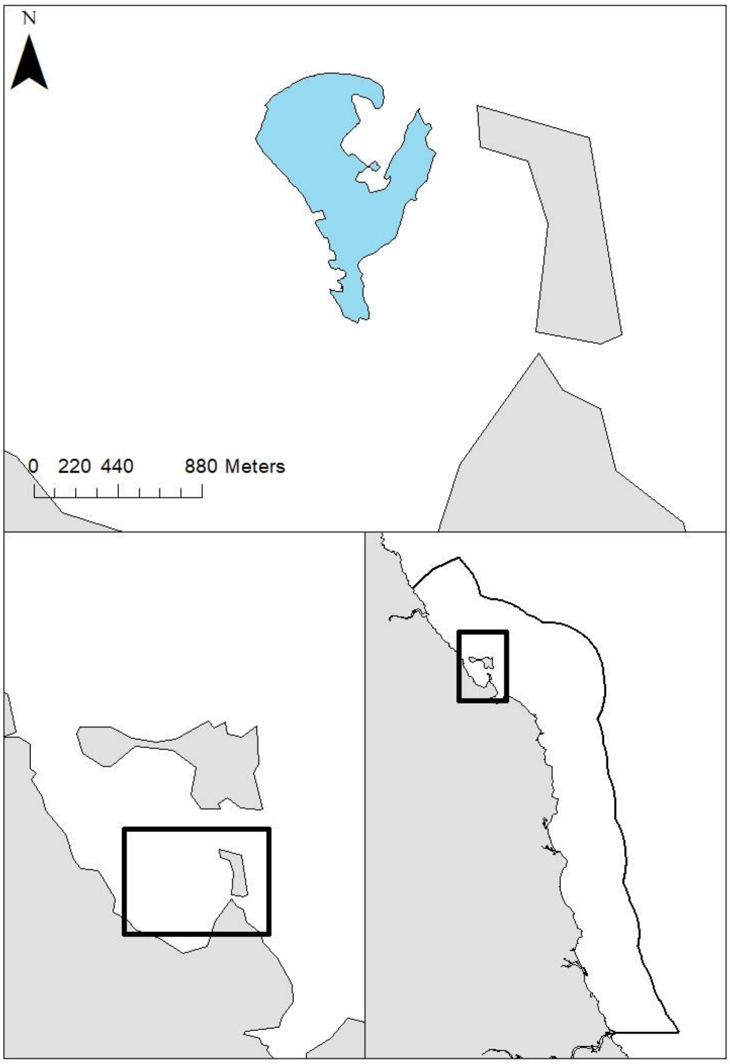

Figure 1: The study area, showing the mussel bed in relation to Holy Island.

Survey Methods

Two Inshore Fisheries & Conservation Officers (IFCOs), one of whom has previously walked the perimeter, walk the perimeter with a handheld GPS. Confidence in the accuracy of the area is low as the area of the mussel bed is difficult to define. There is no WFD definition of what constitutes a mussel bed so it can be subjective to define mussel bed area. The information collected was exported as a GPX file from the GPS using the Garmin GPS software Basecamp and then imported into ARC GIS to map and calculate the area of the mussel bed.

The percentage cover of mussels on the mussel beds were estimated using the 'Walker and Nicholson' survey technique (Walker and Nicholson, 1986). Surveyors walked in a zigzag pattern across the mussel beds, in randomly determined directions, recording the proportion of footsteps landing on live mussels. The total number of steps was selected at random at the start of each transect and ranged from 55 to 300. Percentage cover was then calculated using the following equation:

Percentage Cover = (Number of footsteps landing on live mussels / Total number of footsteps) X 100

A mussel sample was taken at the start and end of each transect from within a $0.1m^2$ sampling quadrat. The samples were sieved and cleaned in intertidal pools to remove sediment. To reduce the impact of the study, the number of quadrat samples taken varied between sites due to the varying quantities and extent of mussels present. The number of mussels per $1m^2$ was later calculated so that further calculations could be compared between sites.

Figure 2: Surveyors using the methodology employed for the Fenham Flats mussel bed survey.

The samples were processed removing dead shells and debris from the living mussels. Total shell lengths of all the mussels sampled were then measured (to the nearest millimetre) using a Vernier calliper and divided into the following size groups: <45mm, 45-54mm and >54mm. The total weight (in grams) of mussels in each size category was also recorded for each sample. The density of mussels on the mussel bed was then calculated the following equation:

$$\text{Mussel Density} = \frac{\text{Number of mussels per m}^2 \times \text{Percentage Cover}}{100}$$

The total biomass of mussels on the mussel bed was then calculated using the following equation:

$$\text{Mussel Biomass (tonnes)} = \frac{\text{Mussel Mass per m}^2 \times \text{Area of Mussel Bed}}{1{,}000{,}000}$$

The estimated total no. of mussels at each site was also calculated using the following equation:

$$\text{Number of Mussels} = \frac{(\text{Area of Mussel Bed in m}^2 \times \text{Number of mussels per m}^2) \times \text{Percentage Cover}^*}{1{,}000{,}000}$$

*Percentage cover as a decimal (e.g. 53.86% would be 0.5386)

In 2019, NIFCA began conducting analysis of the meat content of the mussels found within the Fenham Flats mussel bed to determine if the meat content was declining and to begin recording this data as an additional monitoring tool of overall bed health. This was carried out by weighing a sample of mussels, removing the meat from this sample and recording a wet weight of the meat. The meat content was calculated using the following equation:

$$\text{Meat Content (\%)} = \frac{\text{Weight of Meat}}{\text{Weight in shell}} \times 100$$

Results

For the 2020 survey, a total of 13 samples (all mussel material – live, dead, empty shells – in a $0.1m^2$ sampling quadrat) were taken from the Fenham Flats mussel bed, with a total of 80 live mussels sampled. A summary of the survey results can be seen in Table 2.

Bed Area

In 2020, the overall bed area increased to 52.66ha, compared to the 46ha estimated in the 2019 survey (Figure 3). Throughout the period Fenham Flats has been surveyed by NIFCA there has been a degree of fluctuation in the bed area. Recent years indicate an increasing bed area, however future surveys will determine whether this is simply typical annual fluctuations or an ongoing trend.

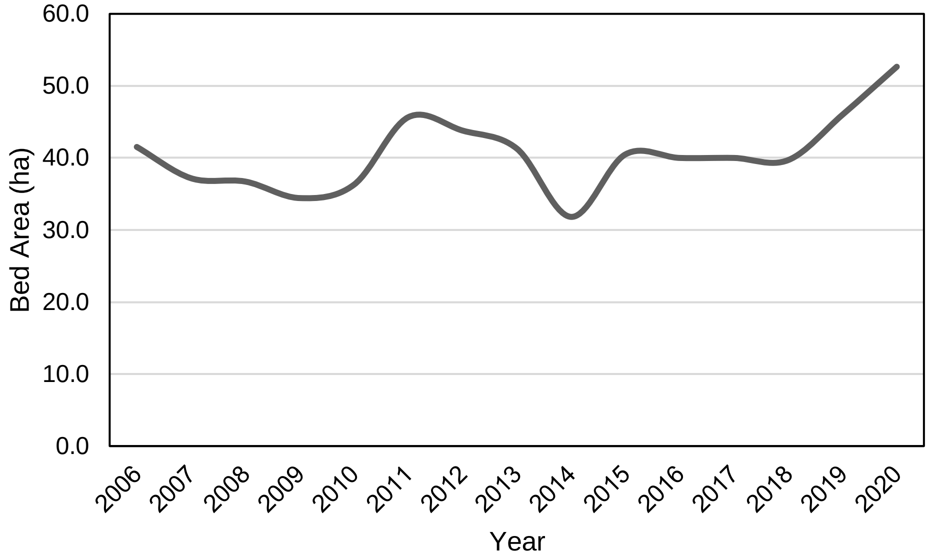

Figure 3: Bed area estimates for Fenham Flats 2006-2020.

Percentage Cover

Percentage cover varied across the site in 2020, ranging from 20-69%, with an overall percentage cover of the mussel bed being estimated at 42.9% (Figure 4). Estimates have fluctuated annually since 2006, with no clear trends throughout this time, although since 2015 there has been a marked annual decline in percentage cover estimates. Despite this, there was a slight uplift in percentage cover in 2020 from the 41.8% estimated in 2019.

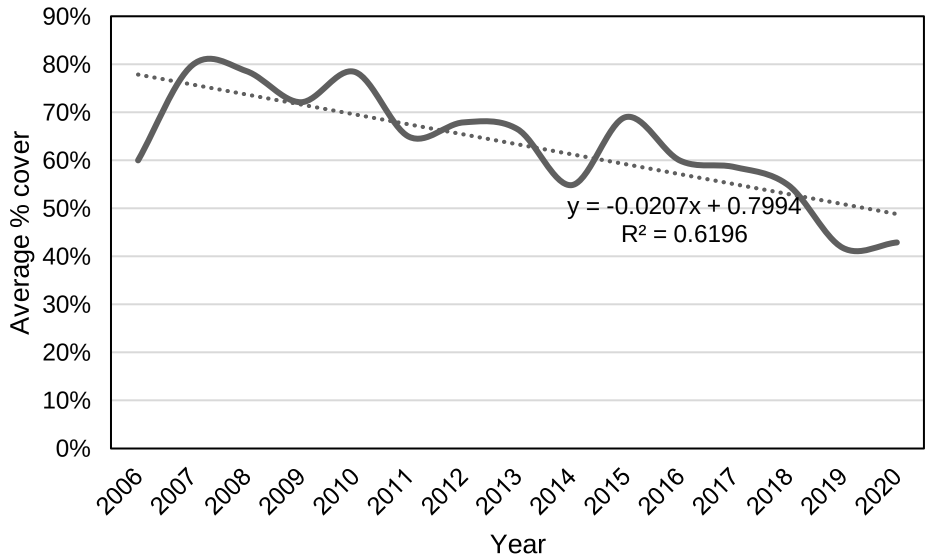

Figure 4: Percentage cover estimates for Fenham Flats 2006-2020.

Mussel Density

Mussel density peaked at the Fenham Flats mussel bed in 2010, at around 1,037 mussels/m^2. Since then, density has declined significantly, to the 29 mussels/m^2 estimated for 2020 (Figure 5), a decline of around 97%.

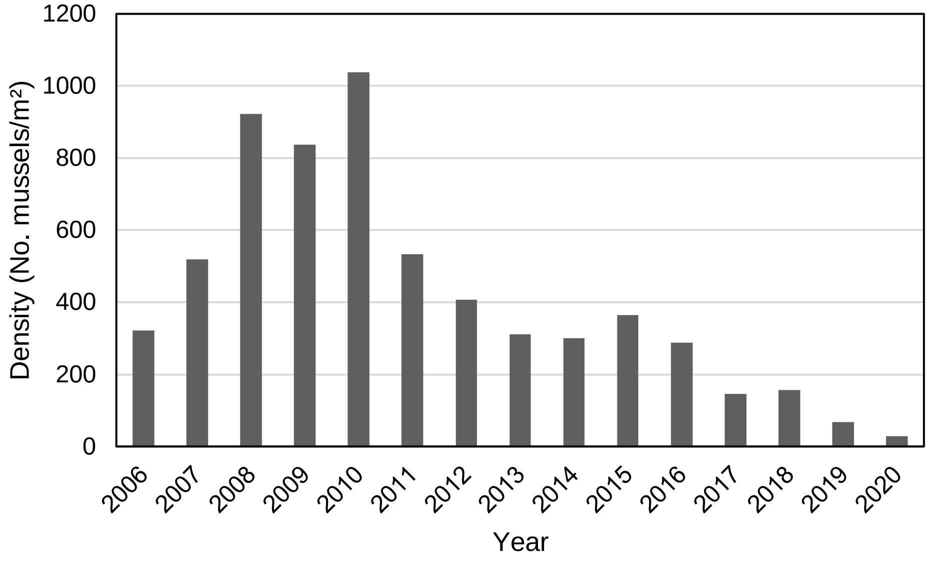

Figure 5: Mussel density estimates for Fenham Flats 2006-2020.

Length Frequency

Despite the survey commencing in 2006, length frequency data was only available from 2013, which is why no earlier information is displayed in this analysis. During the 2020 survey, 80 mussels were sampled, compared to the 180 sampled when the mussel bed was surveyed in 2019. For both years, the population was skewed to a larger mussel size, with very few mussels below 45mm (Figure 6). There has been an observed decline in mussels found in both the <25mm and 25-49mm size classes, which historically comprised a larger proportion of the population (Figure 7). Figure 8 highlights that whilst the frequency of mussels in the >50mm size class has fallen by 78% since 2015 (Figure 7), this larger size class actually dominates the population, with 95% of the mussels sampled in the 2020 survey >50mm. The larger proportion of the population above 45mm for 2020 has contributed to the mean mussel length of 59.95mm, the highest since surveys began in 2006, and an increase of 2.12mm from the previous year. Since the surveys began in 2006, the mean mussel shell length has increased steadily from 41mm to the figures calculated for 2020 (Figure 9). There were fewer mussel recorded below 45mm in the 2020 survey than in previous years. No mussels were recorded below 10mm, with only 3 mussels recorded below 45mm.

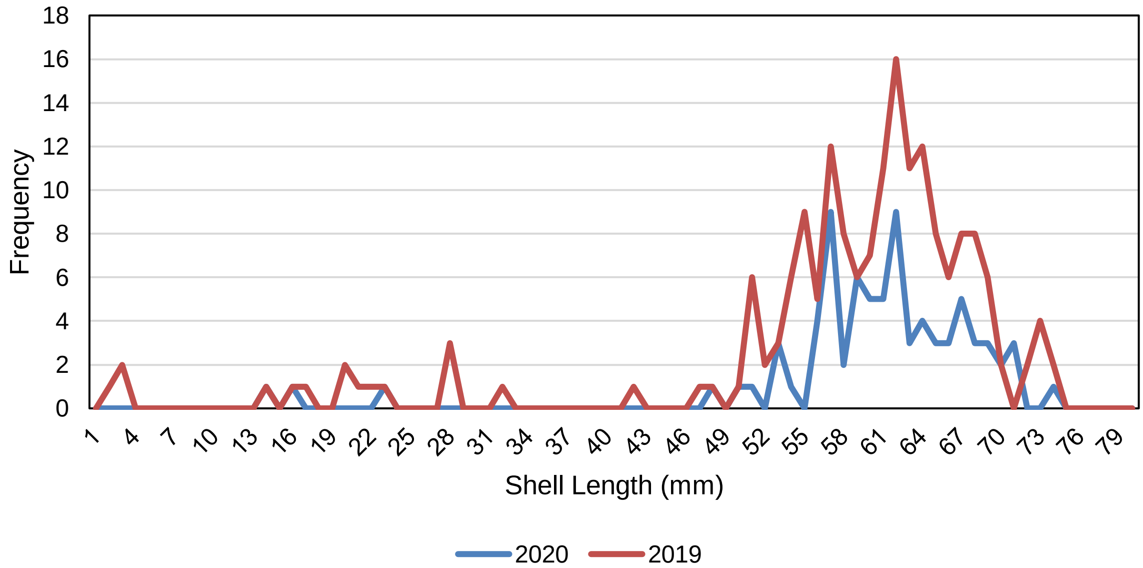

Figure 6: Length frequency for mussels in the 2019 and 2020 survey of Fenham Flats.

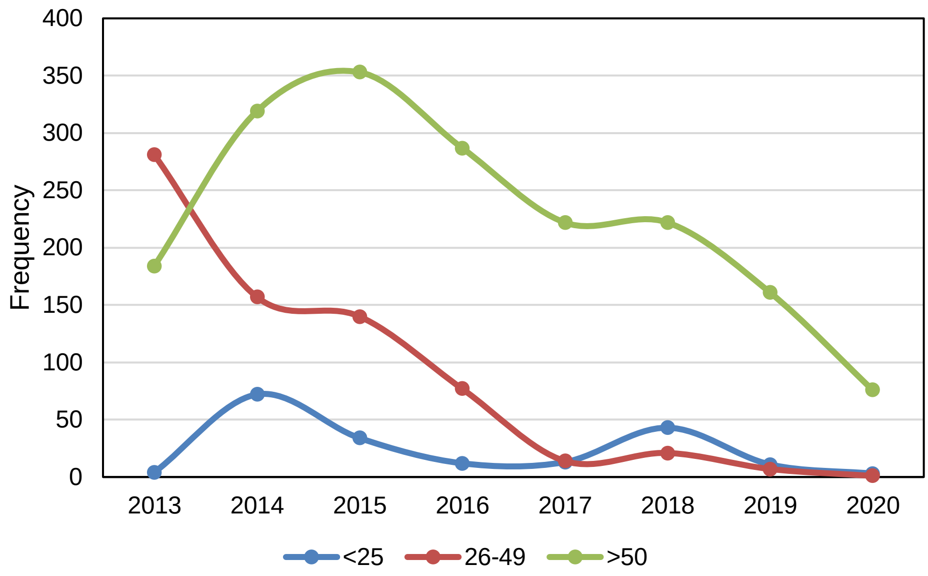

Figure 7: Frequency of sampled mussels between 2013 and 2020 for the <25mm, 26-49mm and >50mm size classes.

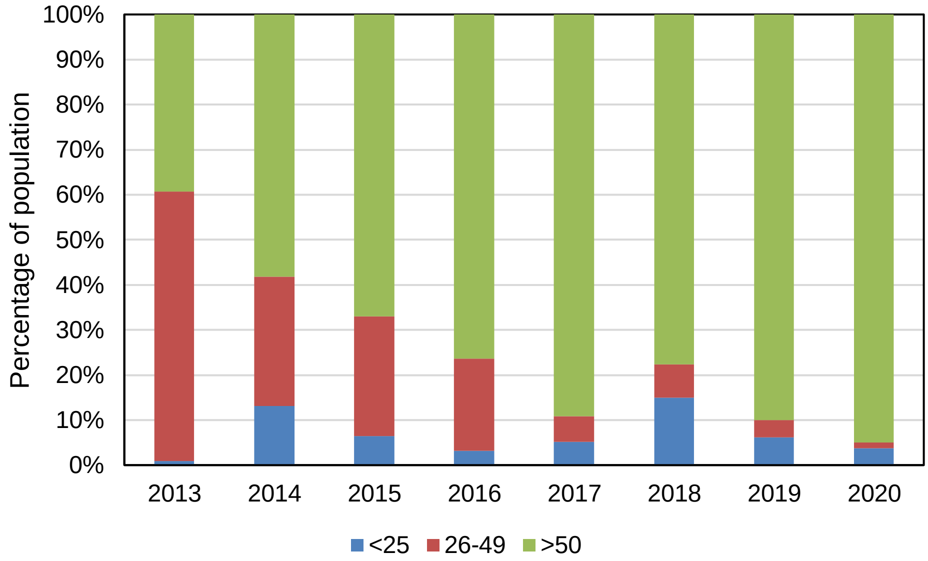

Figure 8: Proportional percentages of sampled mussels between 2013 and 2020 for the <25mm, 26-49mm and >50mm size classes.

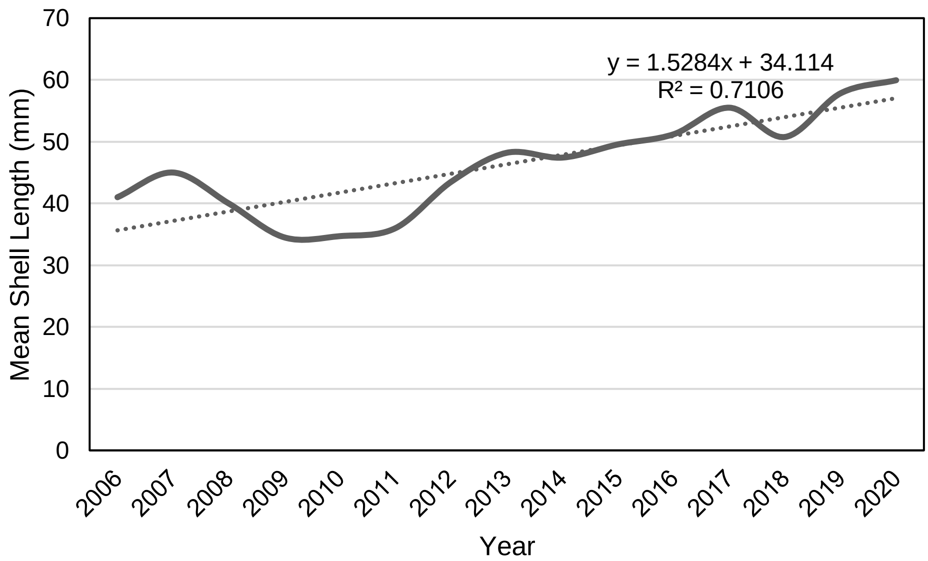

Figure 9: Mean mussel length for Fenham Flats 2006-2020.

Mussel Stock

As expected from the mussel density estimates and the observed declining trends, the total number of mussels at the site has followed a similar pattern of decline since 2020, falling from an estimated 376 million, to 15.4 million in 2020 (Figure 10). Despite the increasing shell size, and as a consequence individual animal weight, the biomass of the site has followed a similar trend of decline. Alarmingly, the rate of decline for both density and biomass appears to be increasing.

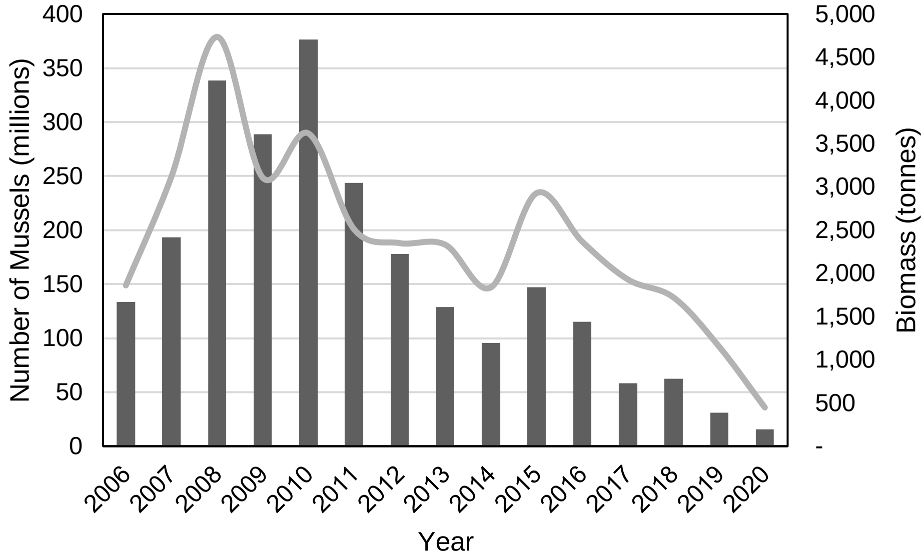

Figure 10: Mussel quantity and biomass estimates for Fenham Flats 2006-2020.

Meat Content

After analysis of the meat content in 2020, there was a slight decrease in meat content in 2020 compared to 2019 (Table 1). The meat content of samples in 2020 was 3.5% lower than the previous year.

Table 1: Meat content analysis of samples taken in 2019 and 2020.

	2019	2020
Shell Weight (g)	997	1,006
Meat Weight (g)	141	107
Meat Content (%)	14.1	10.6

Discussion

Bed area

Since 2018, the bed area has appeared to increase annually. However, prior to this, there have been a number of fluctuations in the bed area, and as such it is important to monitor this going forward to determine if this is another fluctuation, or an ongoing trend. It is worth noting that since surveys began in 2006, the bed area has not expanded year on year, as it has since 2018. To ensure consistency between years, IFCOs that have previously walked the bed are tasked with this aspect of the survey. Consequently, at least one of the two IFCOs walking the perimeter has experience of previously doing so.

Percentage Cover

Annual fluctuations in percentage cover have been observed since the Fenham Flats Mussel Survey began in 2006. Despite this, there is a clear downward trend displayed in the data since 2015. Further study will be continued to monitor this; however, percentage cover may not be a significant indicator of bed health overall, which is why stock biomass is calculated. Thus, all assessed factors of mussel bed health need to be considered holistically.

Density

Mussel density has shown a significant decline since 2010 at Fenham Flats, with density estimates in 2020 97% lower than in 2010. This is cause for concern for this site and will be monitored closely in the coming years by NIFCA. The lower density estimates, similar to percentage cover, could be attributed to an expanding bed area. However, the bed area has not expanded at a comparable rate and cannot account for the decline in density that has been observed. One potential pressure on the bed is the proximity to an aquaculture site for pacific oyster (*Magallana gigas*). The presence of this site may have introduced a led to increased competition for resources, with both *M. gigas* and *M. edulis* being filter feeders, Studies have found that in areas of low flow rates, the presence of oysters has led to a decline in native mussel populations (Joyce *et al.*, 2019). The ecological impacts of invasive species can be severe, but are generally viewed as highly unpredictable, however Invasive species are often associated with higher consumption rates than comparative native species, with these higher per capita metrics predicting ecological impacts (Dick et al. 2013). *M. gigas* has previously been reported to consume mussel veliger, which may have caused a decrease in recruitment at this site. The population of *M. gigas* at the local aquaculture setup has anecdotally been reported as doing well, however there are declines in the mussel population and evidence of lack of recruitment at this site. The introduction of this factor of resource competition to the site may have led to an increasingly rapid decline in the mussels as the oyster farm has increased in scale.

Length Frequency

In 2020, the length distribution for mussels was clearly skewed towards larger sized mussels. The total shell lengths of 96% of the mussels sampled in 2020 were greater than the recommended minimum size of 45mm. Hilgerloh (1997) suggests that dominance by larger sized mussels occurs due to large mussels growing out of the size range exploited by predators. For example, oystercatchers target mussels between 30mm and 45mm in length (Meire and Ervynck, 1986), therefore individuals above 45mm will exhibit lower mortality due to reduced predation. The number of smaller individuals may be lower than expected as 1) smaller mussels may escape through the 5mm mesh of the sieve (however, this does not explain the lack of mussels between 5mm and 44mm) and 2) recruitment may be limited at the site.

Previous reports for this site have highlighted potential issues with spat settlement resulting in a lack of recruitment at the site, resulting in a larger, ageing population. Fewer ‘medium’ sized mussel in the 20-40mm size class range have also been described for mussel beds in the Wash. Here, it is hypothesised that there is a mismatch in timings between a mussel first spawn and nutrient availability. Mussel have been reported to time spawning activity with higher levels of nutrient availability (Myrand et al., 2000). Smaller mussel must put a larger proportion of energetic reserves into reproduction than larger mussel. If the nutrients are not available to replenish depleted reserves this could cause die-off of smaller adult size classes. Larger mussels do not expend the same proportion of energy and so may be able to survive with fewer nutrients post spawning. This would support the trend seen at the site for both frequency of mussels, as well as the proportional estimates of size classes sampled during surveys. The percentage breakdowns of the population by size class highlights that the population is skewed heavily towards animals >50mm in size, highlighting a significant lack of recruitment at the site.

The presence of a *M. gigas* aquaculture popoluation so close to the site could also be a driving factor in this lack of recruitment. The close proximity of *M. gigas* to the site, may result in increased rates of predation on mussel veliger, causing lower settlement rates, ultimately resulting in fewer smaller individuals at the site and causing the population to skew to a larger size.

Mussel Stock

Smaller mussels must put more energy into reproduction and are known to time spawning activity with higher levels of nutrient availability. As previously mentioned in this report, overall mussel abundance biomass estimates at the site are significantly lower than in previous years and have displayed an increasing rate of decline. This is typically indicative of a population that has had poor recruitment in previous years, and as such the population is dying at a greater rate than it is being stocked. At present, NIFCA is unsure of the drivers behind this, however, will continue with surveys to monitor this decline and work with partner agencies to understand further understand these trends and assess whether any intervention is appropriate or required.

Meat Content

The meat content analysis highlighted a slight increase between 2019 and 2020. This could indicate a decline in the health of the mussel population. Meat content is subject to seasonal variation (Okumus and Stirling, 1998), however as the surveys were conducted at similar times, it is unlikely this explains the change. Research has shown that meat content in mussels is indicative of food availability, with a higher meat content being observed when food is plentiful (Orban et al., 2002). Therefore, this change could highlight a lack of food availability. Ongoing surveys shall monitor this trend, as only having data for 2019 and 2020 does not allow for an accurate picture to be built up.

Further Study

NIFCA plan to continue annual surveys of the mussel bed, however further study is needed to determine if there is a lack of recruitment at the site. Other future survey options include

1. A future study could also look at the feeding habits of birds at the site to determine 1) how important mussels are to their diet and 2) what size classes are consumed by which species.
2. Surveys of other mussel beds within the area to determine if factors such as increasing mussel size and decreasing percentage cover are site specific due to the oyster bed or a trend for all mussel beds in the region.
3. Investigate the potential drivers behind the extreme decline in the mussel bed health to understand whether intervention is required.

Conclusion

The purpose of this report is to provide up to date information to inform future management of the site through monitoring of the mussel bed. This study has mapped the perimeter of the mussel bed, estimated percentage cover, density and biomass, and produced a length frequency distribution of the mussels on Fenham Flats. The 2020 results indicate a further decline in the status of mussels at this site, as well as an increased rate of decline than that which has been seen in previous years. NIFCA will use the findings of this report to discuss whether intervention is required at this site and which measure would be appropriate/effective to reduce factors that may influence this reported decline. Further study is still needed to determine:

1. whether the population is naturally skewed towards larger individuals or whether there is a lack of recruitment at the site,
2. potential causes of the decline,
3. whether these improvements continue or if they are a factor of the survey method used.

NIFCA therefore plan to continue annual surveys to monitor the mussel bed.

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Appendices
Appendix 1

Table 2: Summary of results obtained during the Fenham Flats mussel surveys between 2006 and 2018. Showing Area, Percentage Cover, Biomass per m², Density and Total Biomass, Total Number of Mussels and Mean Shell Length.

Year	Area (ha)	% Cover	Total Number of Mussels (millions)	Mean Shell Length (mm)	Density (Mussels per m²)	Biomass (g/per m²)	Total Biomass (Tonnes)
2006	41.527	60	132	41	321.6	4,480	1,861
2007	37.18	79.81	192	45	519.5	8,396	3,122
2008	36.72	78.58	339	40	921.7	12,895	4,734
2009	34.43	72.1	286	34.5	837.8	9,020	3,105
2010	36.28	78.41	381	34.7	1037.3	9,974	3,618
2011	45.65	64.91	243	36	533.5	5,498	2,510
2012	43.8	67.9	178	43.5	406.7	5,364	2,349
2013	41.3	66.5	128	48.2	311.8	5,642	2,330
2014	31.82	54.84	95	47.42	300.5	5,776	1,838
2015	40.49	69.01	147	49.56	363.6	7,232	2,928
2016	44.9	59.95	92	51.2	230.2	5,916	2,654
2017	42.9	58.61	58	55.5	145.9	4,822	2,068
2018	39.7	54.76	62	50.76	156.61	4,336	3,141
2019	46	41.8	31	57.83	67.3	2,503	1,151
2020	52.66	42.9	15	59.95	29.17	851	448