Stock Assessment of the Edible Mussel (*Mytilus edulis*) Beds on Fenham Flats 2021

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Summary

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 2021 survey introduced new descriptive analysis of samples to better understand the spatial population demographics of the Fenham Flats mussel beds. The mussel beds are a biogenic reef, and sub-feature of the Berwickshire and North Northumberland Special Area of Conservation (SAC) and a supporting habitat of Lindisfarne SPA protected birds.

Key results:

- The mussel bed on Fenham Flats in 2021 covered an area of 46.58ha with a percentage cover of 43.5%.
- The estimated values obtained for density have remained similar to the 2020 values, however, have decreased significantly (97%) since surveys began.
- Biomass and total number of mussels have continued on a decreasing trend over recent survey years.
- Mean length of mussels sampled has remained relatively stable since 2013, however has decreased since the 2020 survey.

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 (then English Nature) 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. The beds were harvested for several years, before meat quality was deemed insufficient, and harvesting was discontinued in 2010 NIFCA has continued to carry out annual 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 (Walker and Nicholson, 1986).

Methods

A series of surveys have been conducted on the mussel bed at Fenham Flats annually since March 2005. The 2021 survey was conducted at low water on a spring tide on the 31st March by NIFCA officers.

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).

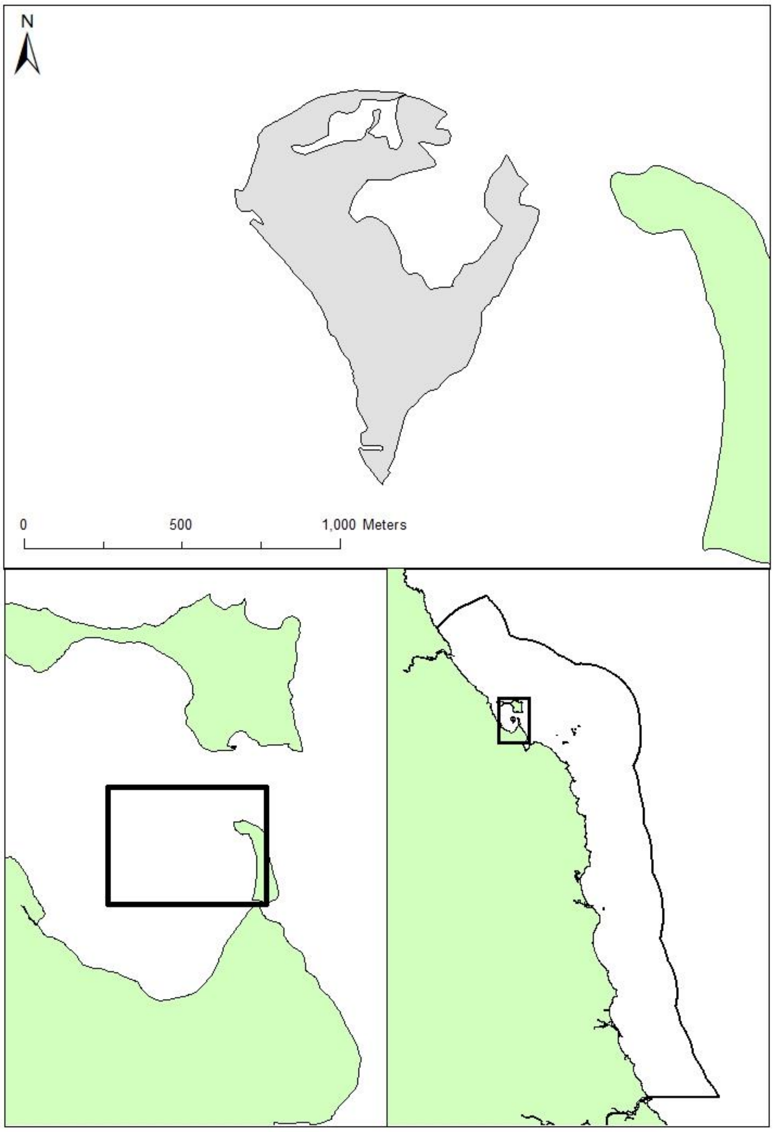

Figure 1: The Fenham Flats mussel bed in 2021, shown in relation to Lindisfarne NNR

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 often 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:

$$Percentage\ Cover\ = \frac{Number\ of\ footsteps\ landing\ on\ live\ mussels}{Total\ number\ of\ footsteps} \times 100$$

A mussel sample was taken at the start and end of each transect from within a 0.1m² sampling quadrat. Location of the quadrats was recorded using a handheld GPS. The samples were sieved and cleaned in intertidal pools to remove sediment. The number of mussels per 1m² 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 using the following equation:

$$Mussel\ density\ (number/m^2)\ = \frac{Number\ of\ mussels\ per\ m^2\ x\ Percentage\ Cover}{100}$$

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

$$Mussel\ biomass\ (g/m^2)\ = \frac{Total\ mussel\ weight\ per\ m^2\ x\ Percentage\ Cover}{100}$$

$$Mussel\ Stock\ Biomass\ (tonnes) = \frac{Area\ of\ bed\ (m^2) \times\ Mussel\ biomass\ (g/m^2)}{1\ 000\ 000}$$

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

$$Number\ of\ mussels\ = Mussel\ Density\ (number/m^2)\ \times Area\ of\ bed\ (m^2)$$

Since 2019, meat content has been measured as an additional monitoring tool of overall bed health. The sample of all mussels was bulk weighed, then boiled for five minutes so that the valve opened. Soft tissue was collected and bulk weighed to calculate the weight of the meat, which was then used to calculate percentage meat content:

$$Meat\ Content\ (\%) = \frac{Meat\ Weight\ (g)}{Total\ weight\ (g)} \times 100$$

Results

For the 2021 survey, a total of 16 samples (all mussel material – live, dead, empty shells – in a 0.1m² sampling quadrat) were taken from the Fenham Flats mussel bed, with a total of 101 live mussels sampled. A summary of the survey results can be seen in Table 1.

Table 1: Results from the Fenham Flats mussel survey from 2006-2021.

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	133.6	41	321.6	4,480	1,861
2007	37.18	79.81	193.2	45	519.5	8,396	3,122
2008	36.72	78.58	338.5	40	921.7	12,895	4,734
2009	34.43	72.1	288.5	34.5	837.8	9,020	3,105
2010	36.28	78.41	376.4	34.7	1037.3	9,974	3,618
2011	45.65	64.91	243.6	36	533.5	5,498	2,510
2012	43.8	67.9	178.1	43.5	406.7	5,364	2,349
2013	41.3	66.5	128.8	48.2	311.8	5,642	2,330
2014	31.82	54.84	95.6	47.42	300.5	5,776	1,838
2015	40.49	69.01	147.3	49.56	363.6	7,232	2,928
2016	44.9	59.95	115.1	51.2	230.2	5,916	2,654
2017	42.9	58.61	58.4	55.5	145.9	4,822	2,068
2018	39.7	54.76	62.2	50.76	156.61	4,336	3,141
2019	46	41.8	31.0	57.83	67.3	2,503	1,151
2020	52.66	42.9	15.1	59.95	28.74	971	511
2021	46.58	43.5	13.6	44.67	29.12	828	386

Bed Area

For the 2021 survey, the overall mussel bed area was estimated at 46.58ha, a decline of 12% from the 52.66ha reported for 2020 (Figure 1, Figure 3 and Figure 4). Whilst there has been a noted decline in bed area since 2020, throughout the period Fenham Flats has been surveyed by NIFCA there has been a degree of fluctuation in the estimated bed area. The estimate of bed area in 2021 is consistent with what had previously been reported in 2019.

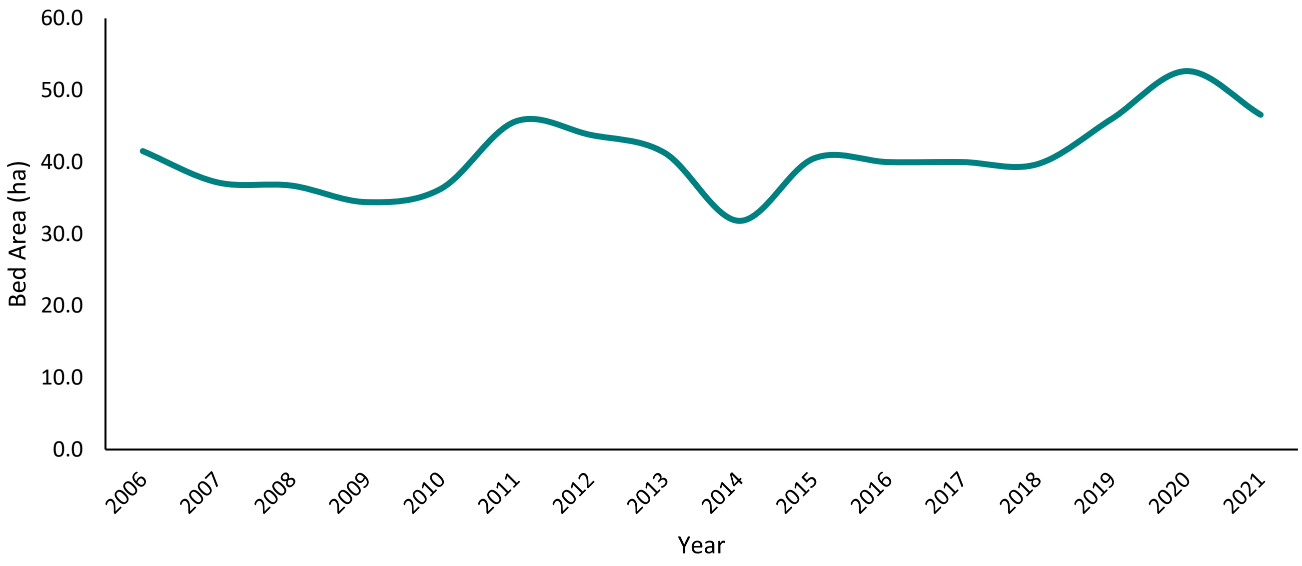

Figure 3: Bed area estimates for Fenham Flats 2006-2021.

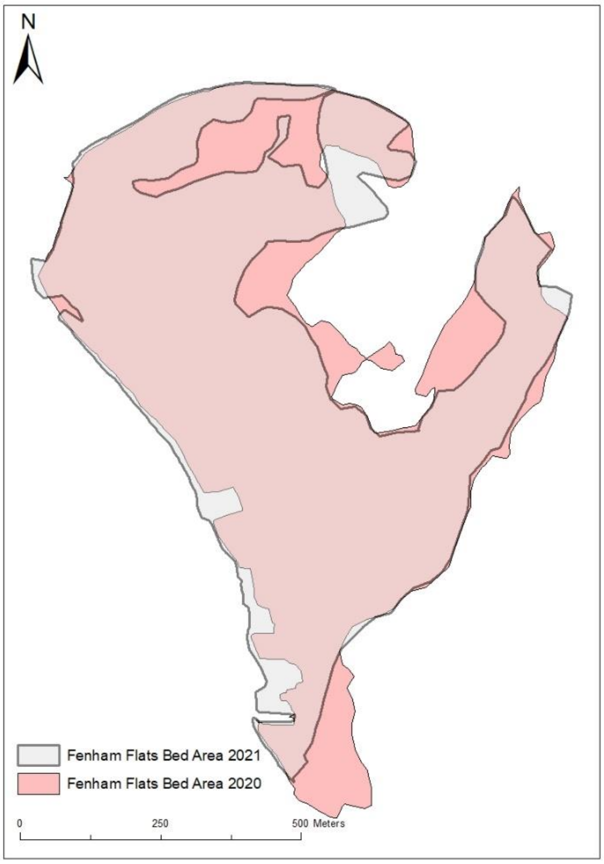

Figure 4: Bed area estimate for 2021 overlayed with the recorded area for the Fenham Flats mussel bed in 2020.

Percentage Cover

In 2021, percentage cover across the mussel bed varied significantly at the sample points, ranging from 16-67%, with overall percentage cover estimated at 43.5%, increasing by 0.6% on the previous year (Figure 5). Estimates have fluctuated annually since 2006, however there is an apparent trend of gradual decline in percentage cover, despite a slight uplift in 2021 from the previous year. Throughout the mussel bed, percentage cover was not distributed evenly (Figure 6), with the areas of highest percentage cover located furthest from the edges of the bed.

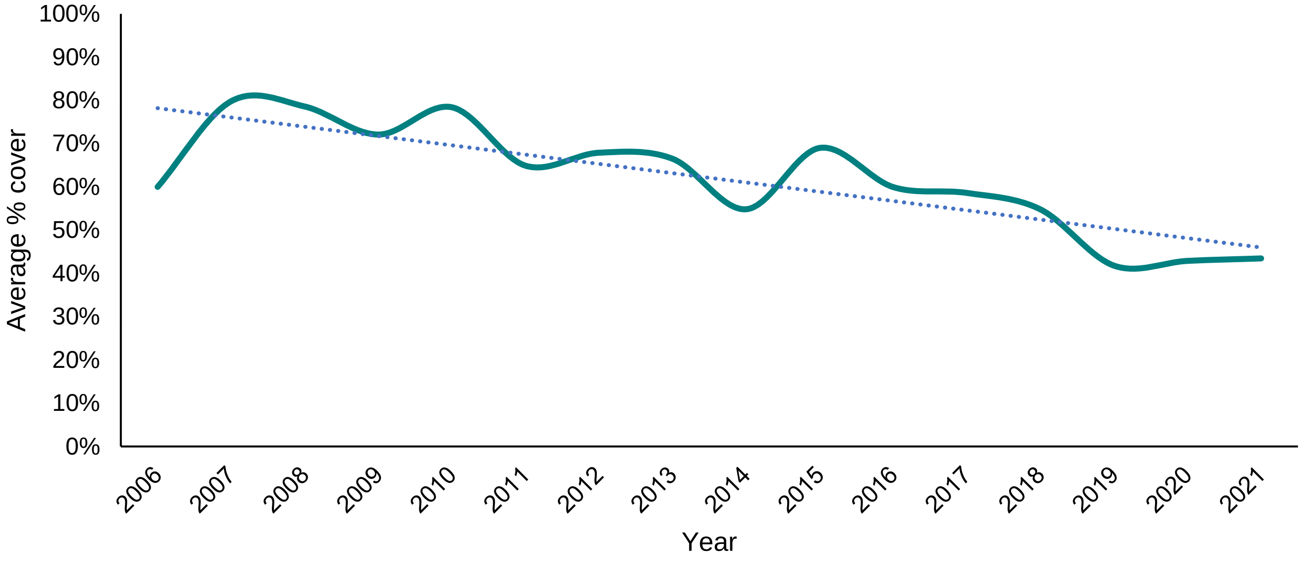

Figure 5: Percentage cover estimates for Fenham Flats 2006-2021.

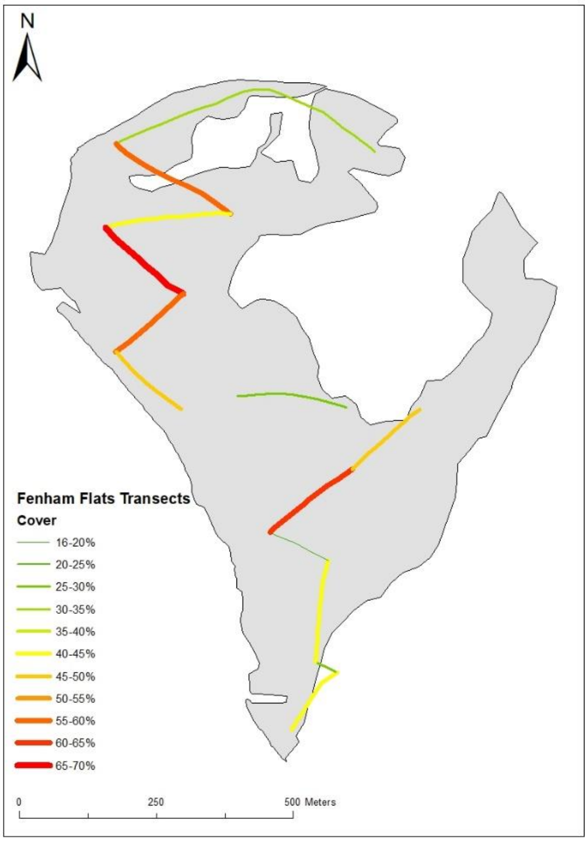

Figure 6: Percentage cover recorded over the transects walked throughout the Fenham Flats mussel bed in 2021.

Mussel Density

Mussel density for the Fenham Flats mussel bed peaked in 2010, at around 1,037 mussels/m^2, however since then density has declined significantly, to 29 mussels/m^2 in 2021 (Figure 7). This is a decline of 97%. Whilst density has increased by 0.4 mussels/m^2 since 2020, there is still a clear trend of decline in overall mussel density at Fenham Flats since surveys began in 2006. Densities of each size class differ to previous year, particularly 2018-2020. In 2021, there is a higher percentage of mussel in the <45mm size class (Figure 10). The slight increase in overall density of mussel could be due to this small increase in juvenile mussel.

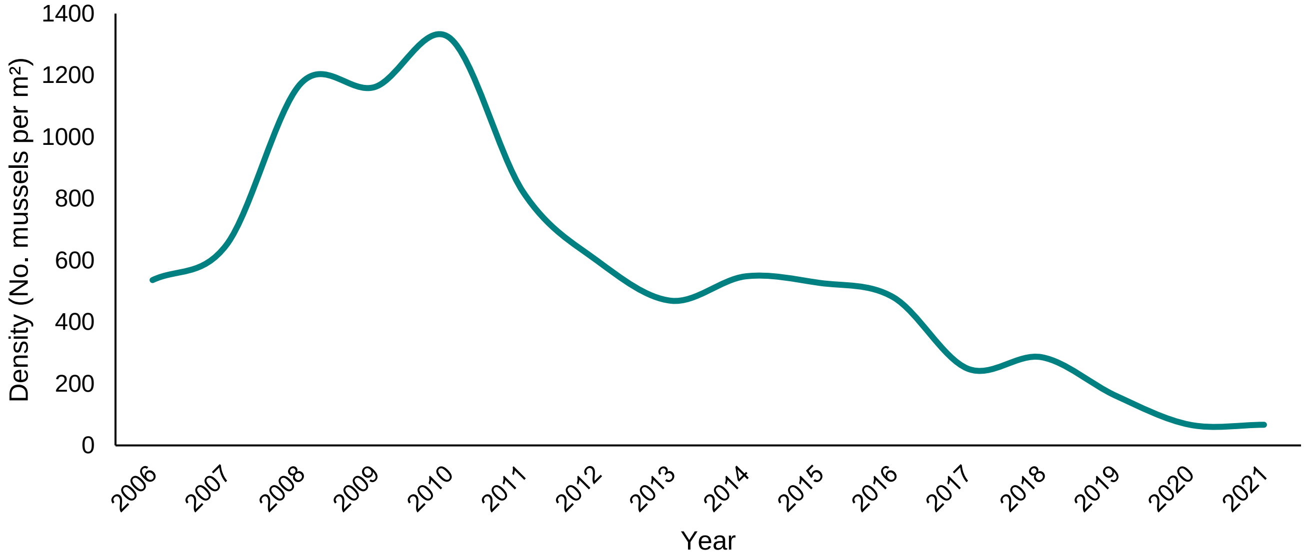

Figure 7: Mussel density estimates for Fenham Flats 2006-2021.

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. In 2021, 101 mussels were sampled from 16 sampling stations throughout the mussel bed. The population conformed to a bimodal distribution, with a notable lack of mussels in the 45-54mm category (Figure 9 and Figure 10). There was an observed increase in the number of individuals in the <45mm category from both the 2019 and 2020 surveys (Figure 10) with an increase in spat mussel recorded in 2021 compared to previous years (Figure 8), although the larger >54mm size class was still the most frequent in samples. Historically the mussel bed was dominated by mussels in the 45-54mm size class, however this is now the least frequent size class at Fenham Flats (Figure 10 and Figure 11). Mussel size varied between sample sites, however there was no clear trend in their distribution throughout the site (Figure 12).

The increase in the number of smaller individuals recorded in samples has also contributed to the fall in the mean shell length found at Fenham Flats. In 2020, mean shell length was 60mm, this has now fallen to 45mm in 2021, the lowest since 2013 (Figure 13). In the 2020 survey, 95% of the mussels sampled were >50mm which would explain the significant difference, as this was the highest mean shell length recorded since 2013. Since 2013, mean shell length has fluctuated annually, but the overall trend is relatively stable. These changes in densities in different length categories reflect the higher abundance of juvenile and spat mussel found in 2021. There was an increase in smaller individuals in 2021 when compared to previous years, with the highest proportion of <45mm mussel recorded since prior to 2013 (Figure 10).

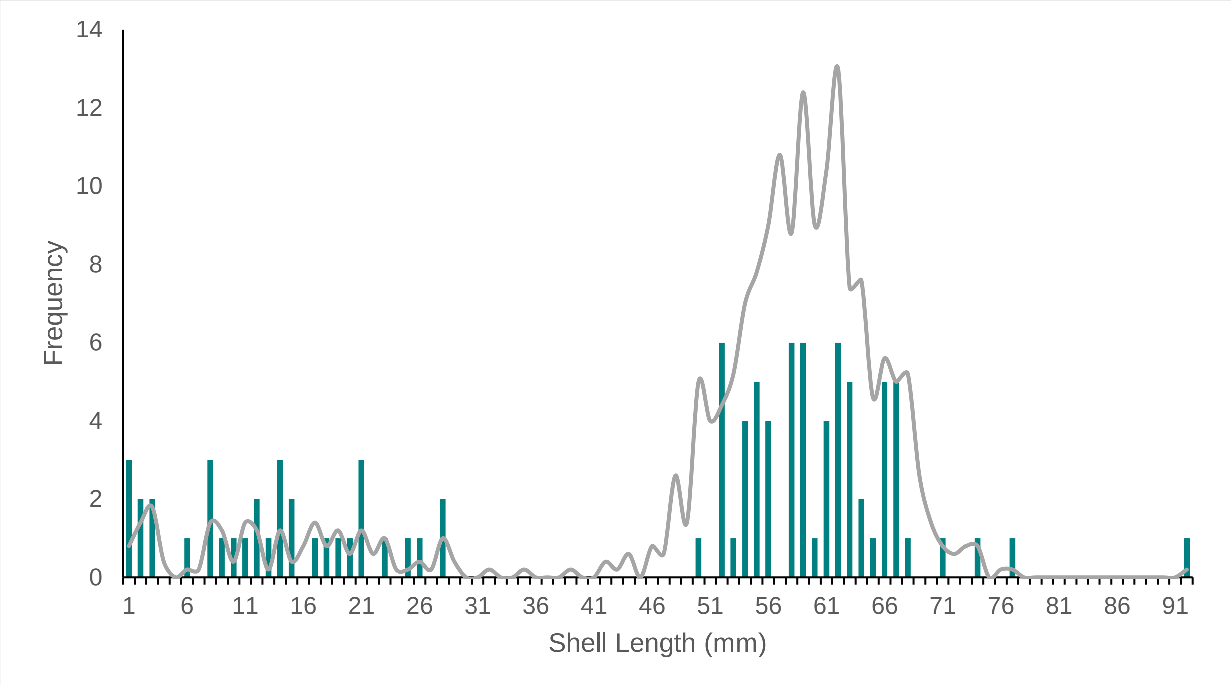

Figure 8 Length frequency (number of individuals in each mm size class) for mussels sampled in the 2021 survey of Fenham Flats (blue bars). Five year averaged length frequency (2017-2021) (grey line).

Figure 9: Length frequency for mussels in the 2021 survey of Fenham Flats.

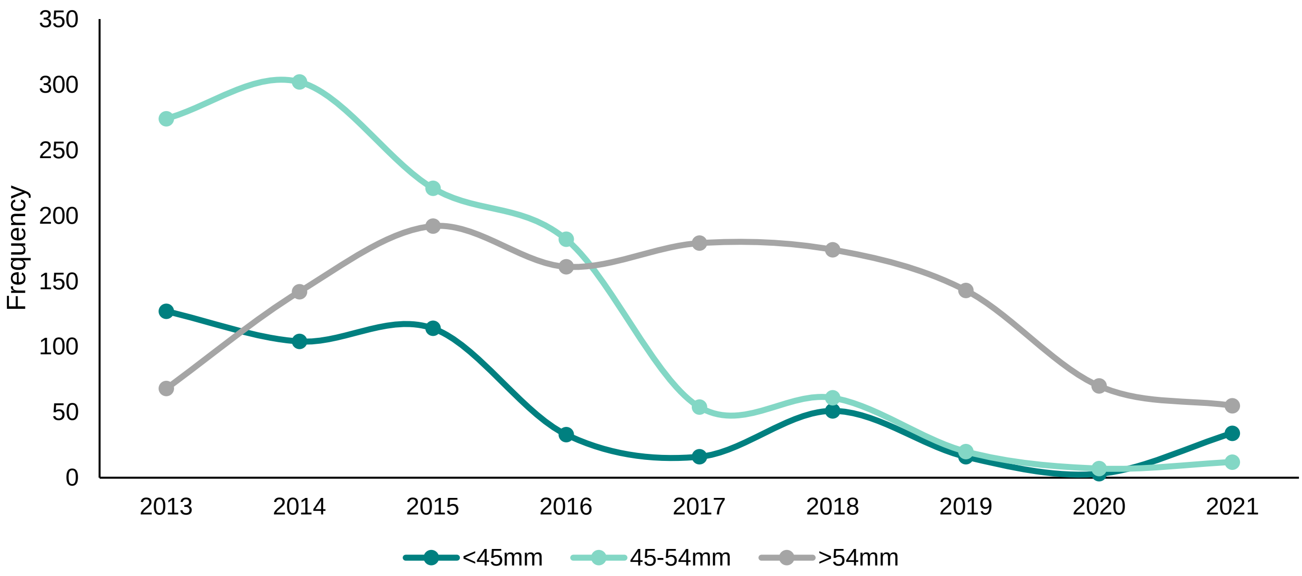

Figure 10: Frequency of sampled mussels between 2013 and 2021 for the <45mm, 45-50mm and 50mm size classes.

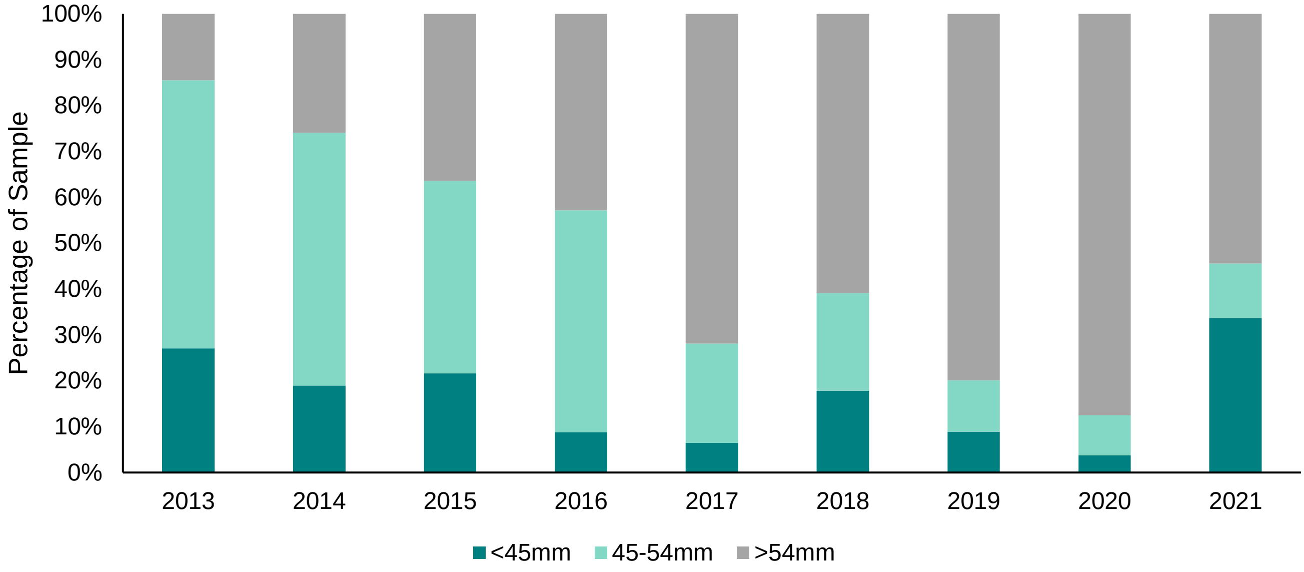

Figure 11: Proportional percentages of sampled mussels between 2013 and 2021 for the <45mm, 45-50mm and 50mm size classes.

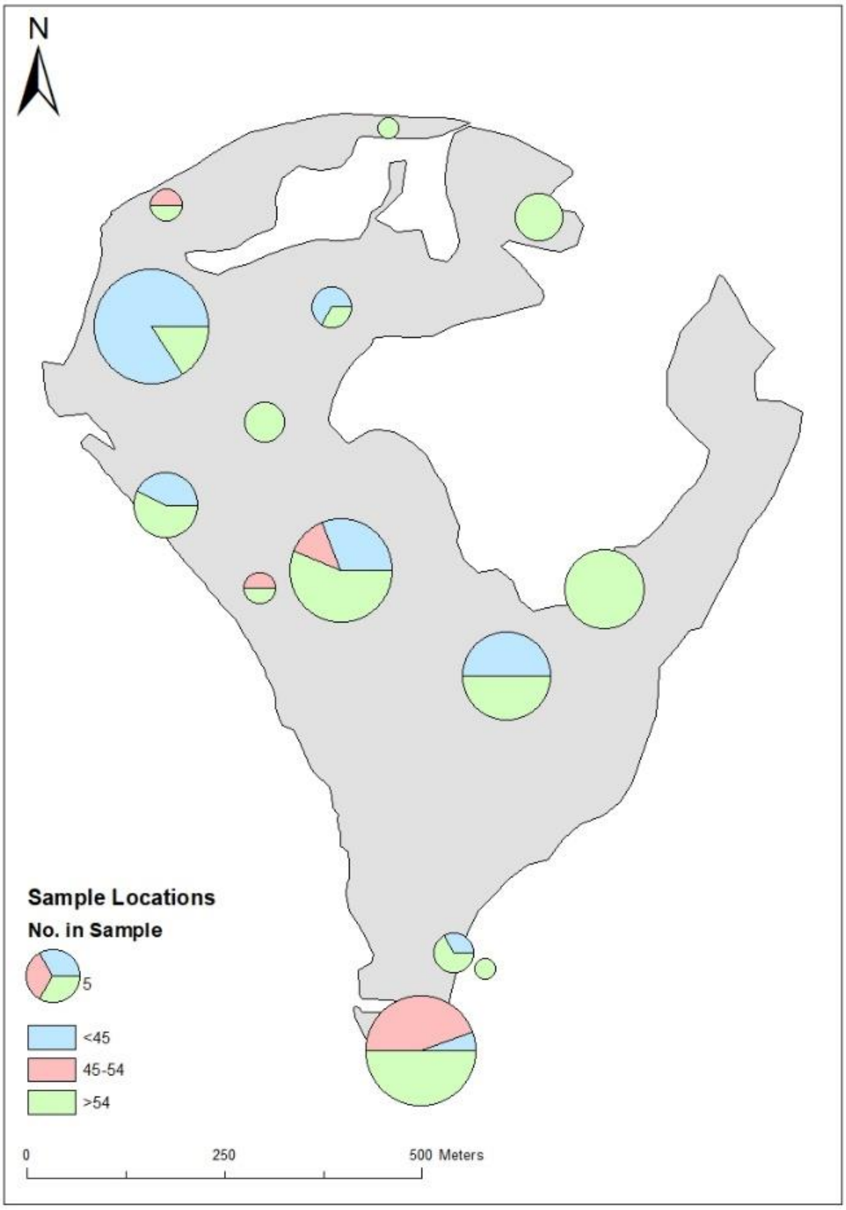

Figure 12: A breakdown for individual sample sites and the proportional percentages of the <45mm, 45-50mm and 50mm size classes. These points have also been proportionately scaled by the number of individuals recorded at each sample site, with sites containing larger sample numbers being displayed larger on the map.

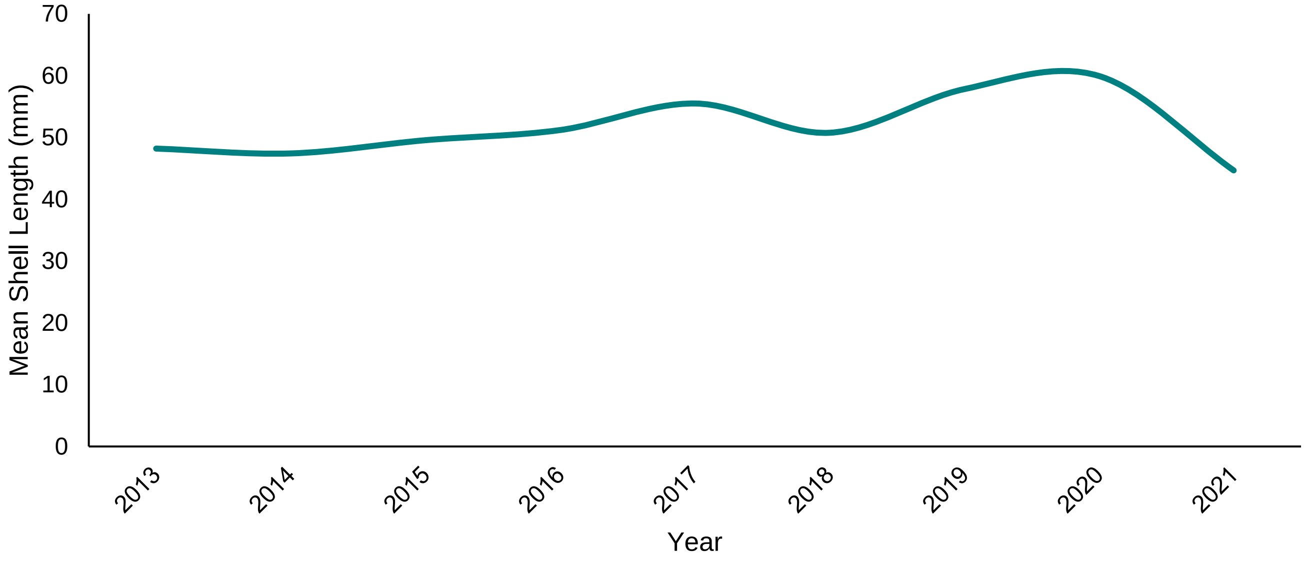

Figure 13: Mean mussel length for Fenham Flats 2013-2021.

Mussel Stock

Total numbers of mussels at the site fell from 15.1 million in 2020, to 13.6 million in 2021, with total biomass following a similar trend, falling from 511 tonnes in 2020, to 386 tonnes in 2021 (Figure 14). Overall since 2006 there has been a significant decline in both biomass and the number of mussels.

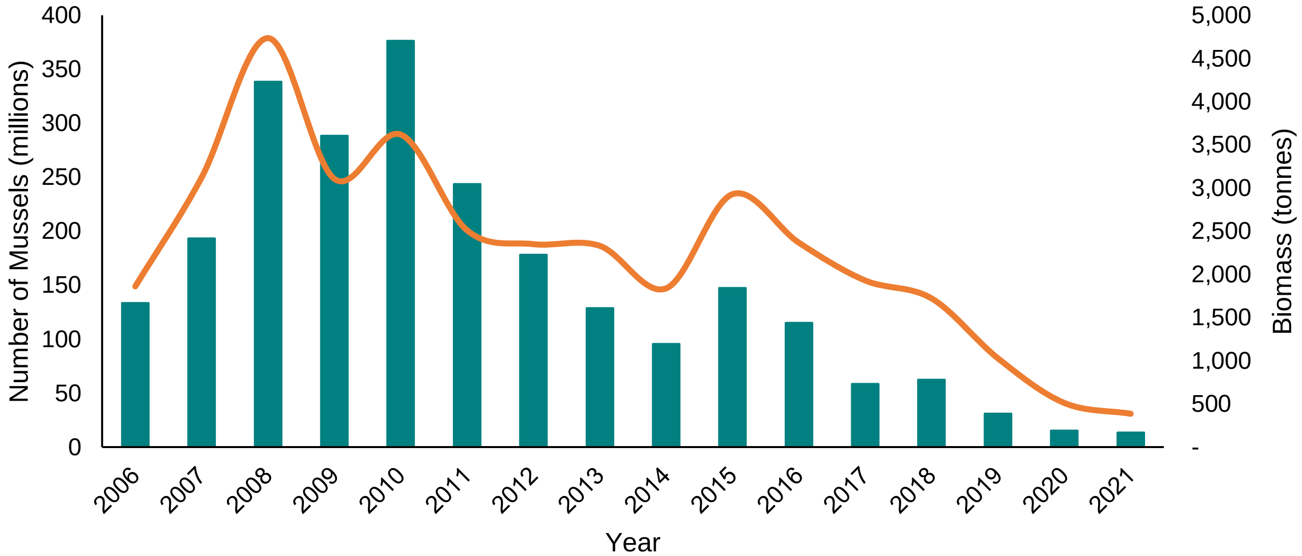

Figure 14: Mussel quantity and biomass estimates for Fenham Flats 2006-2021.

Meat Content

Meat content in the mussels sampled has declined from the 10.6% reported in 2020 to 10% in 2021 (Table 2). Whilst this is a relatively small decline, initial surveys in 2019 estimated meat content of 14.1%, so a declining trend is displayed from findings at the site.

Table 2: Meat content analysis of samples taken for 2019-2021.

	2019	2020	2021
Shell Weight (g)	997	1,006	1,002
Meat Weight (g)	141	107	100
Meat Content (%)	14.1	10.6	10

Discussion

Bed Area

Whilst bed area declined in 2021, this figure has fluctuated annually since 2006, with no clear trend. NIFCA intends to monitor this decline going forward to determine whether this was an annual fluctuation or is indicative of a downward trend in bed area beginning. It should be noted that mapping the perimeter is a very subjective process and as such is very difficult to determine the accuracy and associated confidence in this information. 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 has been a clear downward trend displayed in the data between 2015 and 2019. Since 2019, this decline has halted and there has been a, small increase in percentage year-on-year. Throughout the site, percentage cover was variable, with transects carried out in the centre of the bed area higher than those on the fringes. Given that percentage cover estimates do not rely upon bed area to be calculated, they can be relied upon more so than stock biomass estimates when analysing trends. Despite this, all assessed factors of mussel bed health need to be considered holistically.

Mussel Density

Mussel density has shown a significant decline since 2010 at Fenham Flats, with density estimates in 2021 97% lower than in 2010, although the density recorded in 2021 was similar to that observed in 2020. This may be indicative of a stop to the declining trend, although it is too soon to determine whether this is correct. This will be monitored by NIFCA going forward. 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 veligers, which may have caused a decrease in recruitment at this site (Joyce *et al*., 2019). That being said, the large number of small individuals of mussels found in the 2021 survey may suggest that recruitment at the site is increasing. 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 historically there has been 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.

Anecdotal evidence suggests that mussel beds throughout the northeast have seen a decline overall. Historically, northeast beds were more widespread, with a sudden reported decline in 2009, from which they have never fully recovered. This has been seen elsewhere in the UK, for example, populations in the Wash and in Scotland have reportedly decreased in abundance at ~54% of the sites surveyed between 2002-10 and 2014-15. This was the largest decline of any intertidal species recorded in the survey (Burrows *et al.*, 2014/15). *M. edulis* beds have also been 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).

It is unclear of the exact drivers in the decline at Fenham Flats, and whilst the nearby aquaculture site may be an influencing factor, there are a number of other factors that may also drive this decline. Typically, bait collection and gathering for human consumption are causes of decline (Maddock, 2008 and Fenton, 1978). However at Fenham Flats, these activities do not occur, so can be eliminated from the list of potential threats. Water quality and pollution could be influencing the mussel population at the site (Hilgerloh, 1997), with predation, water temperature and climate change also potentially attributing to the changes observed (Dent, 2019). NIFCA is currently investigating this further as part of a collaborative MSc project with Newcastle University which will look at potential causes of this decline. This project will analyse water quality data provided by the Environment Agency, alongside our survey results to determine if there is a relationship between the water quality and the reported mussel population, as well as investigating any other drivers of decline in the area.

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. The survey of the site in 2021 found the population demonstrated a bimodal distribution, with evidence of increased recruitment at the site than in previous years. 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 in samples may be lower than is actually found at the site as smaller mussels may escape through the 5mm mesh of the sieve or may not be identified within the sample itself.

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. One hypothesis is 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. Additionally, competition by pacific oysters in the immediate adjacent farm may lead to reduced nutrient (feeding on zooplankton and phytoplankton in the water column) availability with interspecific predation by pacific oysters of mussel veligers further reducing recruitment.

Mussel Stock

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. Extent estimates form part of the calculation of stock therefore confidence in these determinations are medium, but downward trends of recruitment, percentage cover and density over time are high. 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. The slight increase in recruitment observed in 2021 may indicate that there is hope for this mussel bed and that there has been a shift in the quantity of recruitment at the site. 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 decrease between 2019 and 2020, with a further, albeit smaller, decline in 2021. 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 from 2019 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 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.

The problems in estimating mussel bed area are due to their subjective nature and the difficulty of assessing mussel bed edges on the ground. A current project at Newcastle University aims to use an unmanned aerial vehicle (UAV or drone) to determine whether this method is effective at surveying intertidal habitats such as mussel beds, and early results from the Blyth estuary indicate it could be useful for helping determine mussel bed extent and coverage that could supplement NIFCA survey data and aid in determining bed area over time using historical satellite and drone imagery. Project outcomes include a standard operating procedure for using UAVs for intertidal research within the equipment capabilities of NIFCA. NIFCA hopes to use its own drone capabilities for future mussel surveys to further validate findings by officers in the field.

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 2021 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. Further study is still needed to determine:

1. whether the bimodal distribution observed in 2021 is indicative of better recruitment at the site than observed in previous years, or whether this was simply anomalies in the samples collected,
2. potential causes of the overall 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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