Assessment of the Edible Mussel (*Mytilus edulis*) Bed on Fenham Flats 2022

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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, with samples of mussels were collected, and total shell length and weight were measured. The 2022 survey continued with the descriptive analysis of samples, started in 2021, 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 2022 had a percentage cover of 17.4%.
- The estimated values obtained for density have significantly declined since 2021, following the overall trend since the peak in 2010.
- Biomass and total number of mussels have continued on a decreasing trend over recent survey years.
- Mean length of mussels sampled increased since 2021, but is still below what has been observed between 2013-2020.

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 2022 survey was conducted at low water on a spring tide on the 22nd 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). The mussel bed perimeter could not be calculated in 2022, and as such, the 2021 bed area was used.

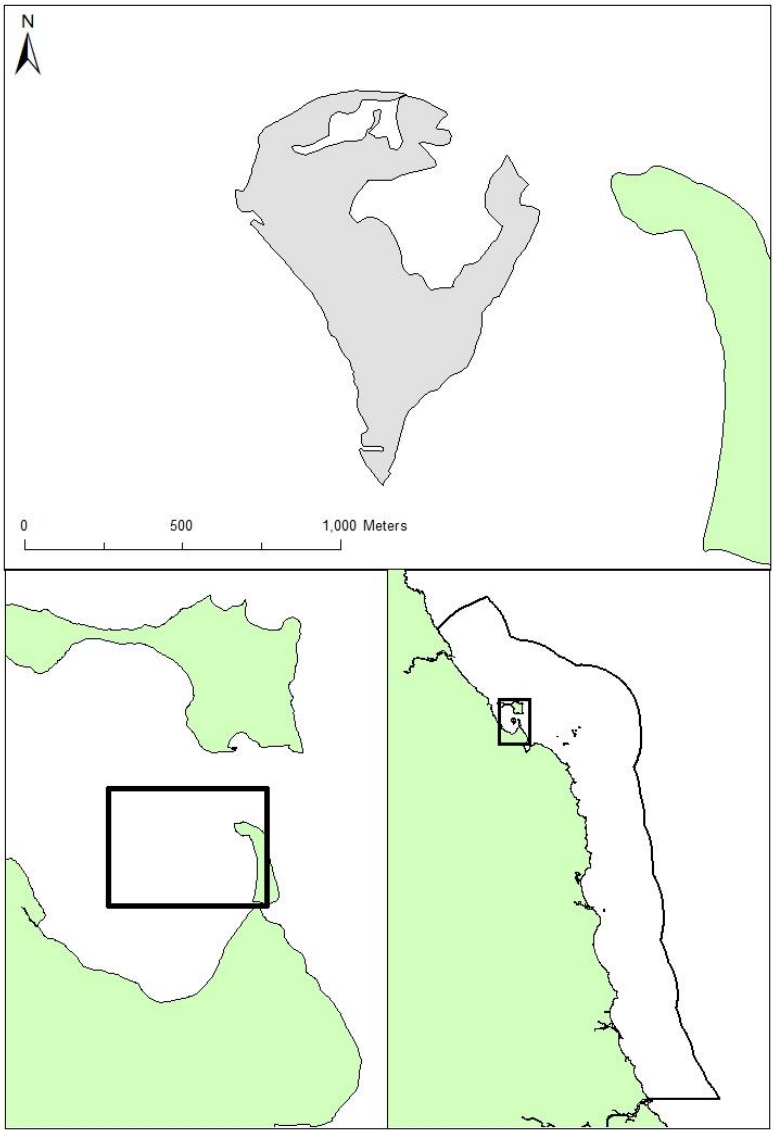

Figure 1: The Fenham Flats mussel bed in 2021, shown in relation to Lindisfarne NNR.

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. Due to an error with the 2022 data, the perimeter could not be defined. There is no WFD definition of what constitutes a mussel bed so it can be subjective to define mussel bed area. The information previously 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 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 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:

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

Results

For the 2022 survey, a total of 20 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 51 live mussels sampled. A summary of the survey results can be seen in Table 1. Due to the bed area in 2022 being unable to be calculated, the bed area from 2021 has been used in the analysis of the data.

Table 1: Results from the Fenham Flats mussel survey from 2006-2022.

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	54.8	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	43.47	13.6	44.67	29.12	828	386
2022	46.58*	17.39	2.1*	47.35	4.43*	149	70*

*calculated using 2021 bed area

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 (Table 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.

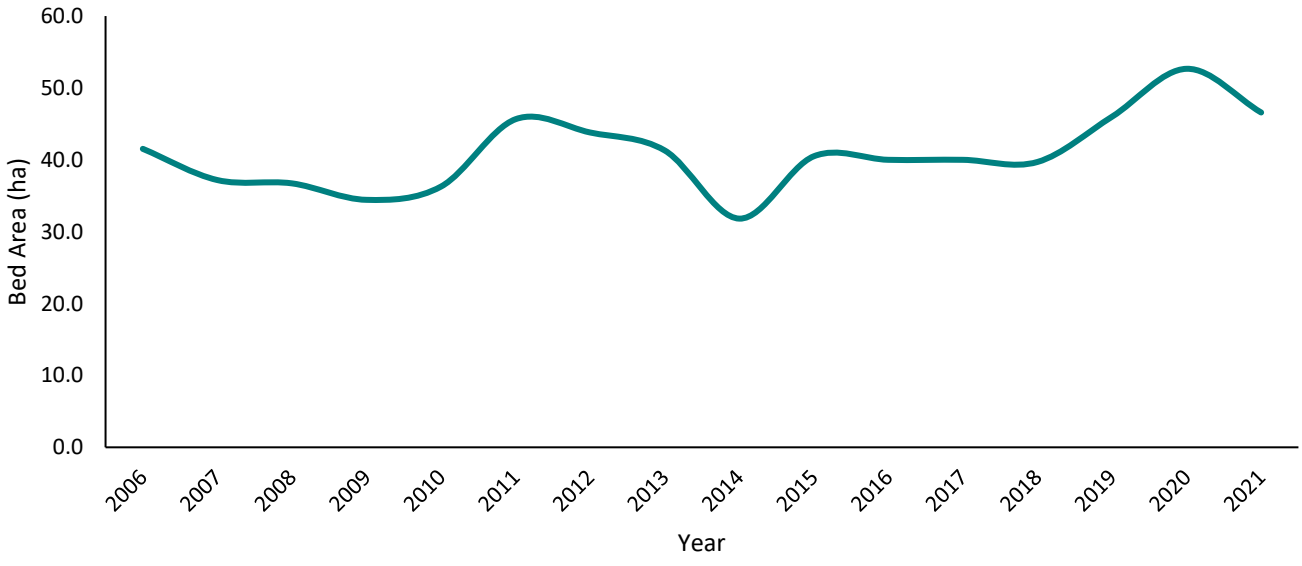

Figure 3: Bed area estimates for Fenham Flats 2006-2021.

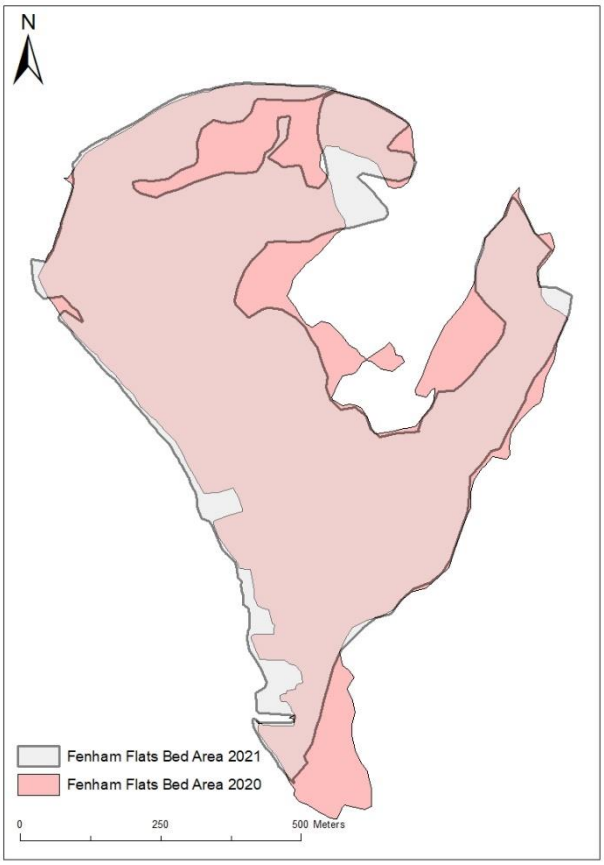

Figure 4: Bed area estimate for 2021 overlayed with the recorded area for the Fenham Flats mussel bed in 2020.

Percentage Cover

In 2021, percentage cover across the mussel bed varied significantly at the sample points, ranging from 1-43%, with overall percentage cover estimated at 17.4%, falling by 26.1% from 2021 (Figure 5). Estimates have fluctuated annually since 2006, however there has been an apparent trend of gradual decline in percentage cover until 2022, where the percentage cover has fallen dramatically. Throughout the mussel bed, percentage cover was not distributed evenly (Figure 6), however the south of the mussel bed exhibited the highest percentage covers. The northern side of the mussel bed had significantly lower percentage covers, even when compared to previous years (Figure 6).

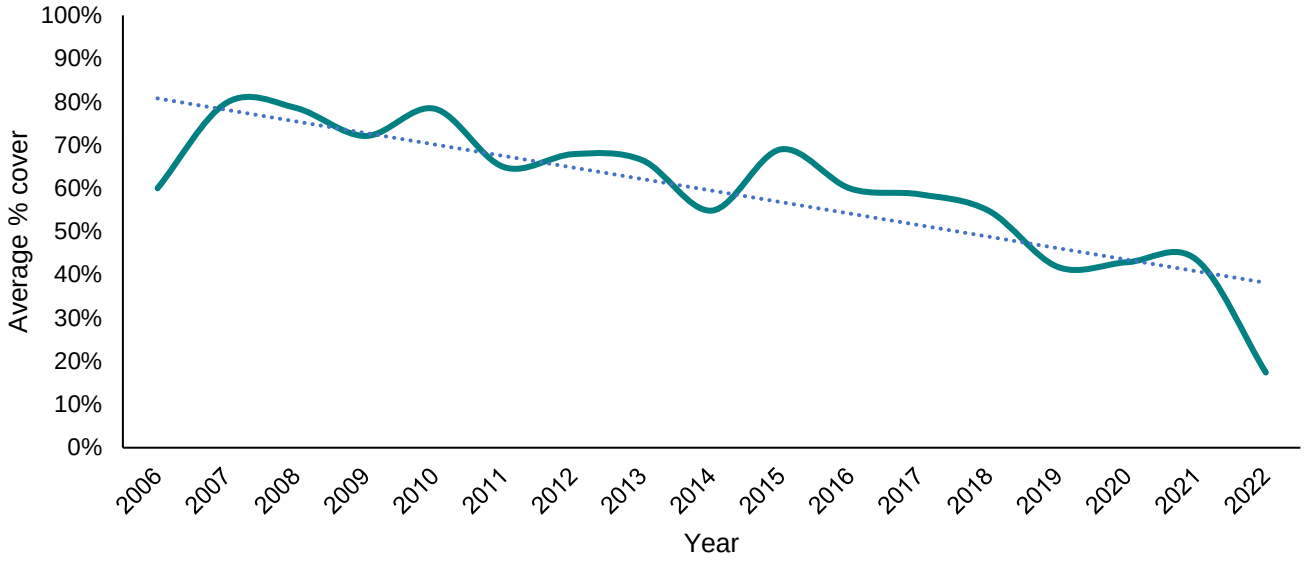

Figure 5: Percentage cover estimates for Fenham Flats 2006-2022.

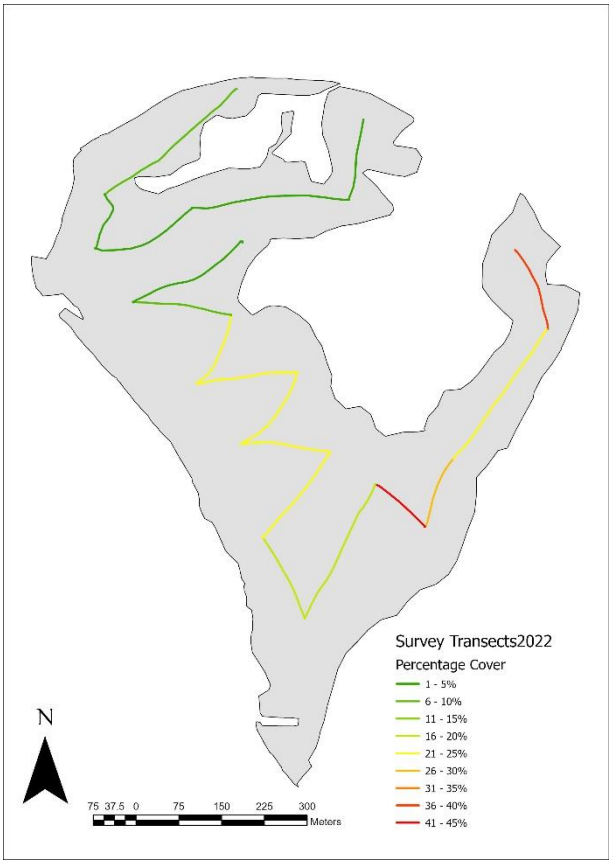

Figure 6: Percentage cover recorded over the transects walked throughout the Fenham Flats mussel bed in 2022.

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 4 mussels/m^2 in 2022 (Figure 7), dropping from 29 mussels/m^2 in 2021. This is a decline of 99.6% from the peak in 2010. Whilst mussel density has declined steadily since 2010, the density dropped significantly in 2019 and has continued this rapid rate of decline.

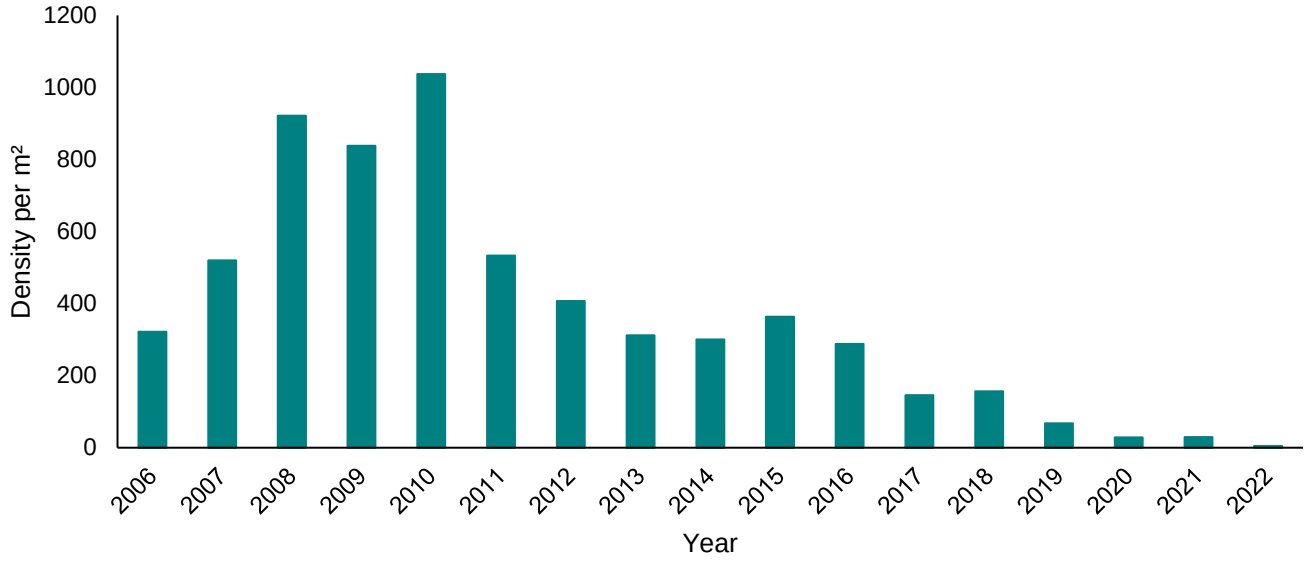

Figure 7: Mussel density estimates for Fenham Flats 2006-2022.

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 2022, 51 mussels were sampled from 20 sampling stations throughout the mussel bed. The population continued to conform to a bimodal distribution, with a notable lack of mussels in the 45-54mm category (Figure 8 and Figure 9). In 2022, there continued to be an increased proportion of individuals in the samples in the <45mm category, as was observed in 2021 (Figure 9). The percentage of mussels within the sample that measured <45mm, was 33%, similar to the 34% recorded in 2021 (Figure 10). Despite this, the >50mm category was still the most dominant in the samples, accounting for 65% of the mussels sampled (Figure 10). 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 9 and Figure 10). Mussel size varied between sample sites, however there was no clear trend in their distribution throughout the site, although the most densely populated areas were in areas away from the bed edge (Figure 11).

As a result of a large number of mussels in the samples collected in 2022 measuring >59mm, there was an observed increase in the mean shell length from previous years. Mean shell length in 2022 was 47.35mm, increasing from 44.67mm in 2021 (Figure 12). The increase in the number of smaller individuals recorded in samples in 2021 likely contributed to the fall in the mean shell length found at Fenham Flats in previous years. In 2020, mean shell length was 60mm, which fell to 44.67mm in 2021, the lowest since 2013 (Figure 12). The presence of only one mussel measuring between 45-54mm in length has likely been a contributing factor in the mean mussel length increasing in 2022.

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 and 2022. There was an increase in smaller individuals in 2021 and 2022 when compared to previous years, with the highest proportion of <45mm mussel recorded since prior to 2013 (Figure 10).

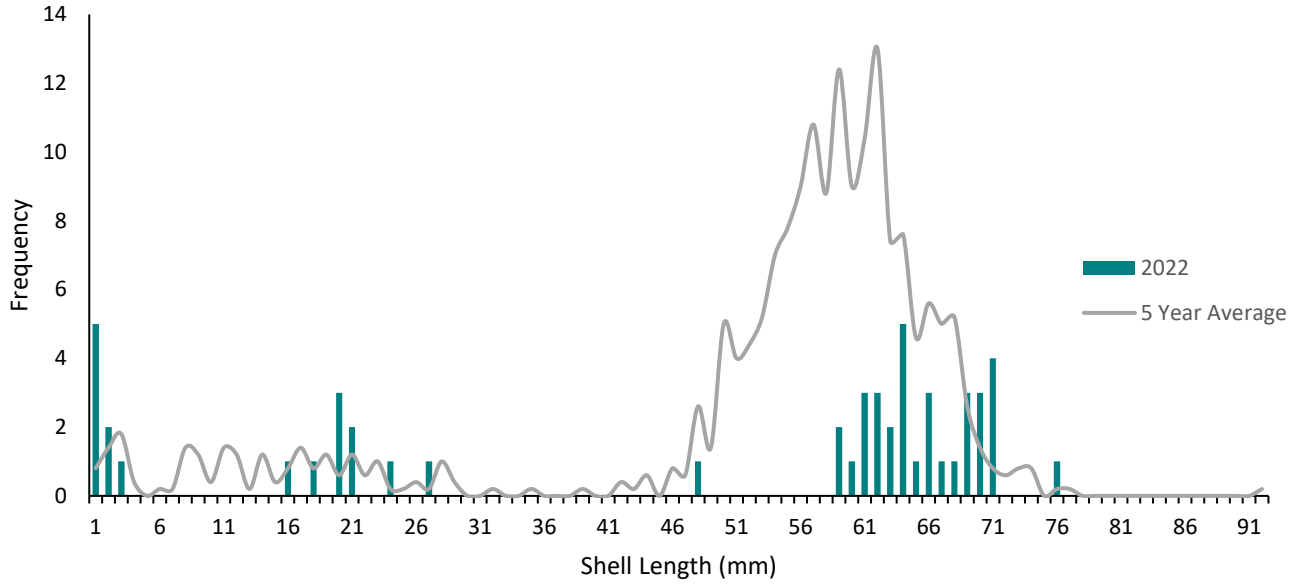

Figure 8: Length frequency (number of individuals in each mm size class) for mussels sampled in the 2022 survey of Fenham Flats, as well as the 5-year average frequency for the

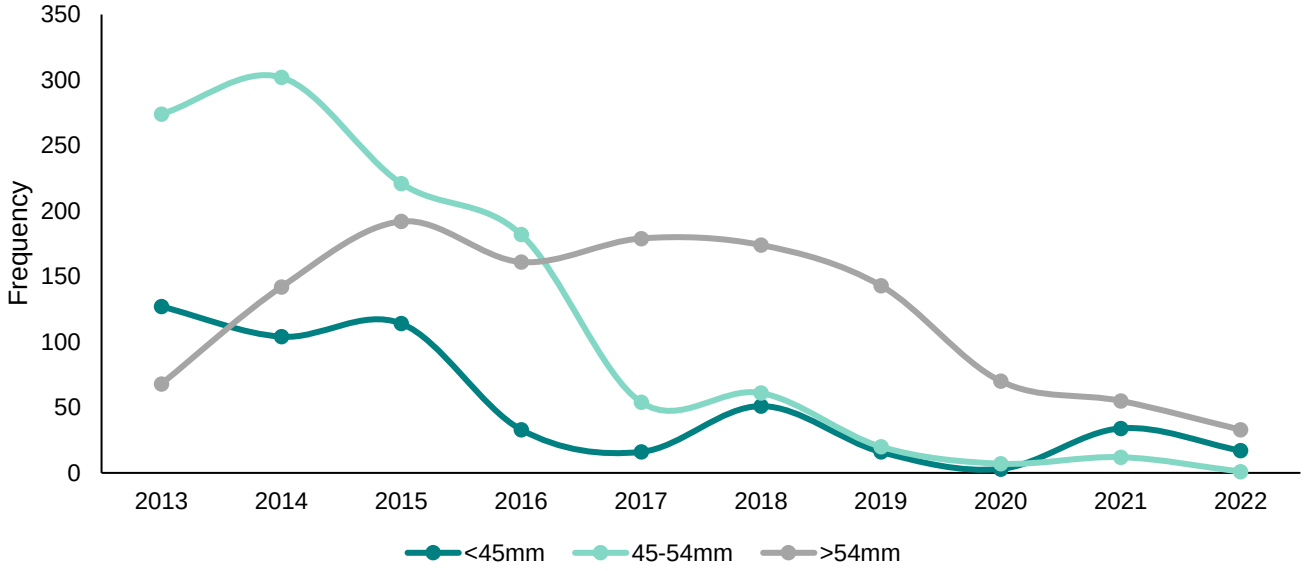

Figure 9: Frequency of sampled mussels between 2013 and 2021 for the <45mm, 45-50mm and 50mm size classes.

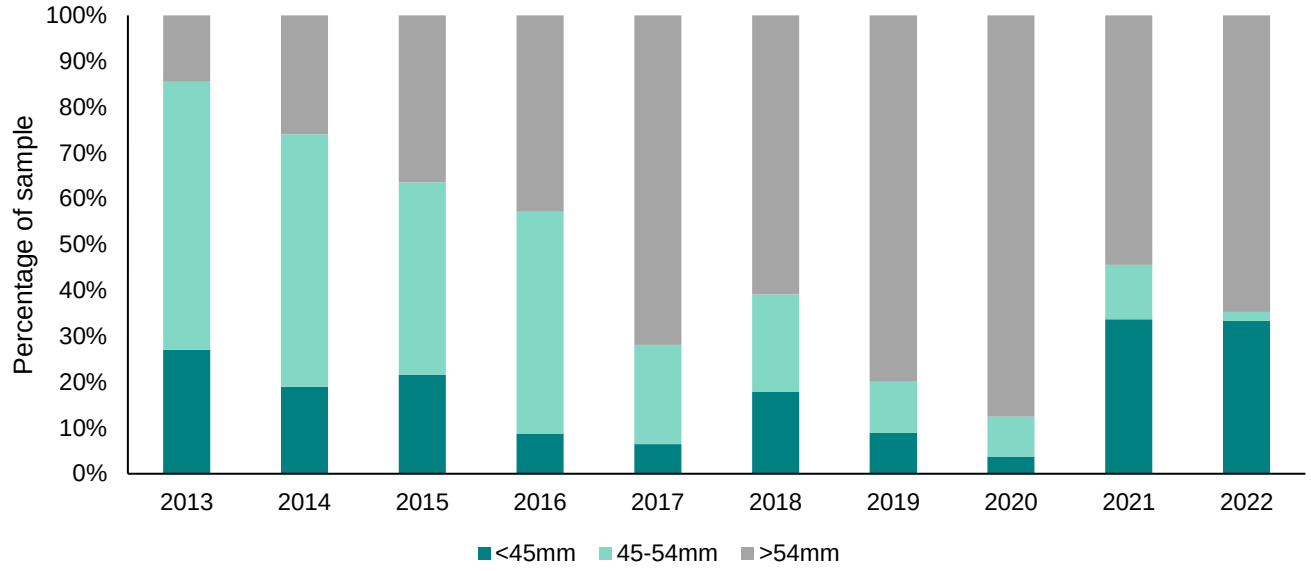

Figure 10: Proportional percentages of sampled mussels between 2013 and 2021 for the <45mm, 45-50mm and >50mm size classes.

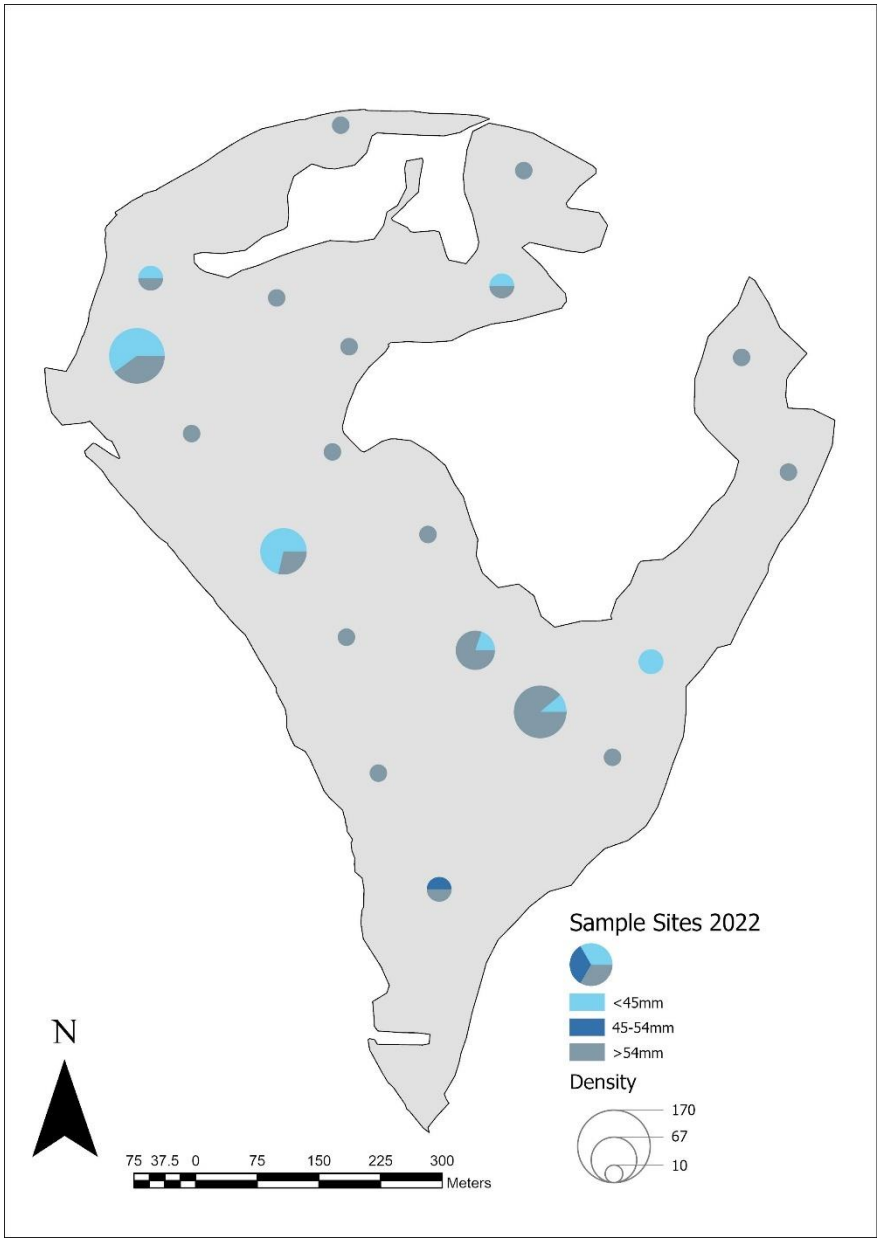

Figure 11: A breakdown for individual sample sites and the proportional percentages of the <45mm, 45-50mm and 50mm size classes. These points have also been proportionately scaled by the number of individuals recorded at each sample site, with sites containing larger sample numbers being displayed larger on the map. The bed area shown is the mussel bed calculated in 2021, with the 2022 sample sites plotted over it.

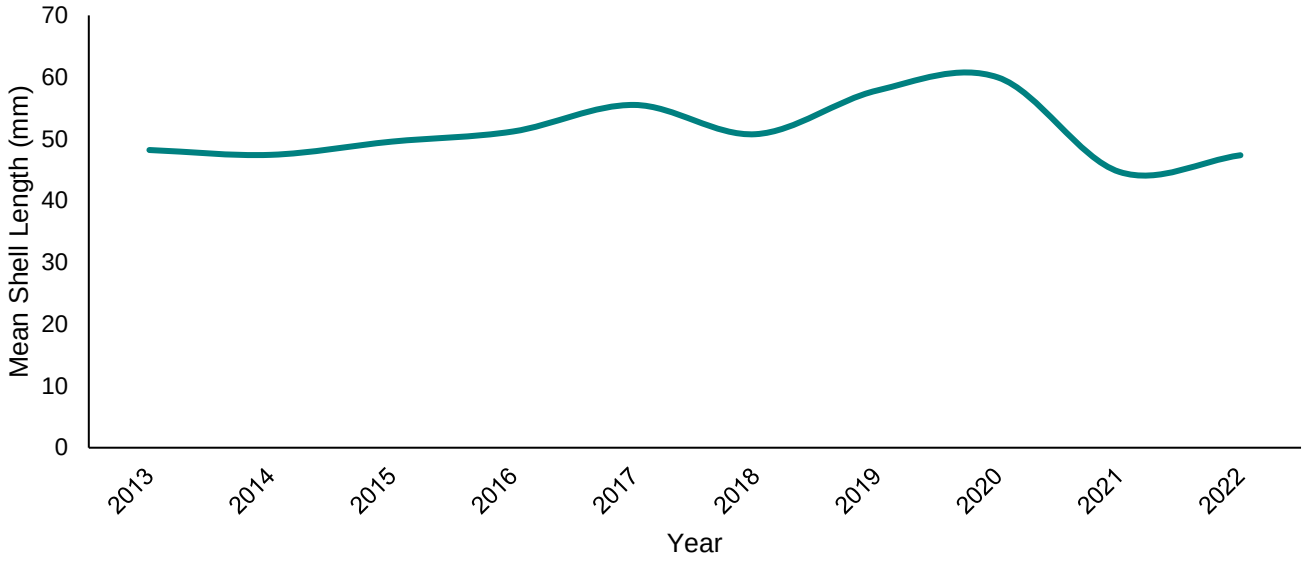

Figure 12: Mean mussel length for Fenham Flats 2013-2022.

Mussel Stock

Due to the bed area from 2021 being used in the analysis of the 2022 data, there is little confidence in the mussel stock analysis for 2022. Anecdotally there did not appear to be any significant changes in the bed area for 2022 from 2021. Based on the bed area data for 2021, and using the mussel survey data from 2022, it is estimated that total numbers of mussels at the site fell from 13.6 million in 2021, to 2.1 million in 2022, with total biomass following a similar trend, falling from 386 tonnes in 2021, to 70 tonnes in 2022 (Figure 13). Overall since 2006 there has been a significant decline in both biomass and the number of mussels.

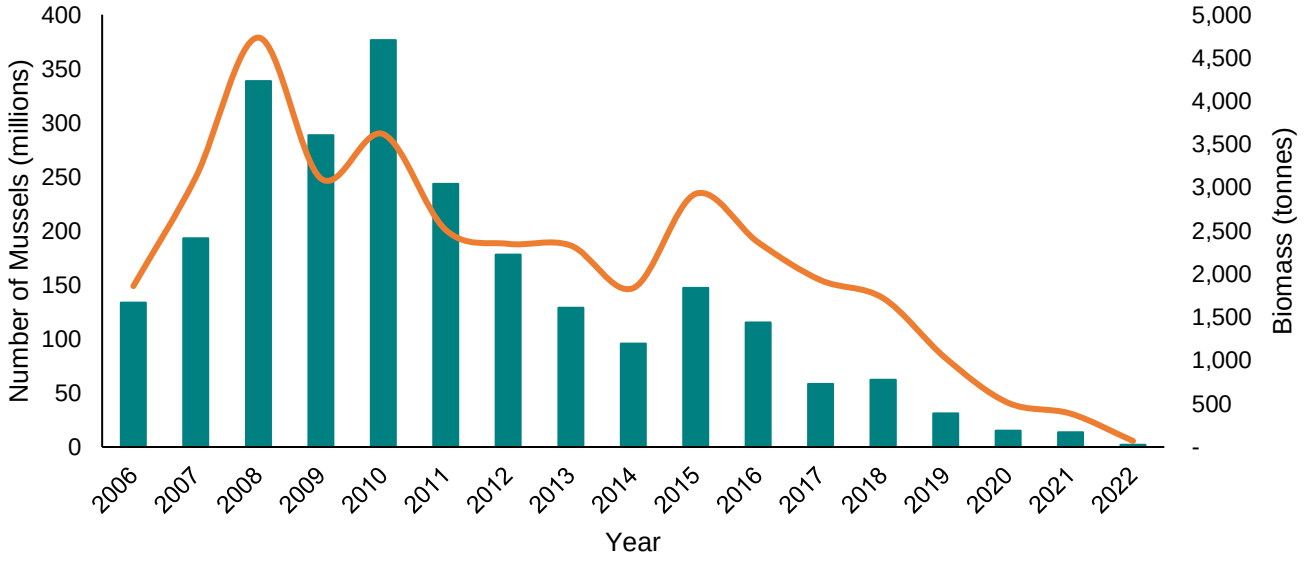

Figure 13: Mussel quantity and biomass estimates for Fenham Flats 2006-2022.

Discussion

Bed Area

Due to the bed area being unable to be calculated in 2022, the 2021 data was used. Anecdotally the bed area is not said to have changed significantly since 2021. 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 since 2015, with a significant decrease between 2021 and 2022.Throughout the site, percentage cover was variable, with transects carried out in the centre of the bed area higher than those on the fringes. There does appear to be a trend that indicates that the northern part of the mussel bed showed significantly lower percentage cover that the southern portion of the bed. It is unclear why this is; however, we will monitor this going forward. 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. A study by a student from Newcastle University has found that percentage cover of mussel beds in the Lindisfarne area show a significant negative correlation with PBDE154 a polybrominated diphenyl ether which (a banned flame retardant) and dieldrin and endrin (banned pesticides). These bio contaminants may be affecting *M. edulis* populations at Lindisfarne due to increased storm events, but it is unclear if this is seasonal (Richardson, 2021).

Mussel Density

Mussel density has shown a significant decline since 2010 at Fenham Flats, with density estimates in 2022 99.5% lower than in 2010. Density did stabilise between 2020 and 2021, but this does not seem to have continued in to 2022.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).

Length Frequency

The survey of the site in 2022 found the population demonstrated a bimodal distribution, which was also reported in 2021, 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, the lack of an accurate bed area for 2022 makes analysis of the mussel stock with any significant confidence very difficult. Despite that, the anecdotal reports that the bed area has not significantly changed since 2021, it could be inferred from the data that there has been a decline of the mussel stock at the site, the extent of which is unknown for 2022, as a result of the lack of bed area information. From the information available, albeit with varying degrees of confidence, overall mussel abundance 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 low, but downward trends of recruitment, percentage cover and density over time are high. This trend 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 and 2022 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.

The biomass estimates per m^2in 2022 can however be relied upon, as this does not factor in the bed area when it is calculated. There was an alarming and notable drop in the biomass estimates for 2022 when compared to 2021, falling by 82%. It is unsure why this decline was observed, but

future survey work will assess whether this is the start of an alarming trend of significant decline in the bed, or just an annual fluctuation, or has arisen because of the random nature of the sampling employed as part of this survey methodology.

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 project at Newcastle University aimed 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 2022 results indicate a further significant and stark 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 2022 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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