Stock Assessment of the Edible Mussel (*Mytilus edulis*) Bed on Fenham Flats 2023

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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 2023 survey continued with the descriptive analysis of samples, started in 2022, 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 2023 had a percentage cover of 4.4%.
- The estimated values obtained for density have significantly declined since 2022, 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 in 2023 when compared to 2021 and 2022, 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 2006. The 2023 survey was conducted at low water on a spring tide on the 23rd March by NIFCA officers and Natural England Volunteers.

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 2023.

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 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 100 to 313. 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 using the following equation:

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

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

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 2023 survey, a total of 18 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 19 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 2006-2023.

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*
2023	48.10	4.37	0.2	48.32	0.52	19	9

*calculated using 2021 bed area

Bed Area

For the 2023 survey, the overall mussel bed area was estimated at 48.1ha, an increase of 3% from the bed area in 2021, but a 7% decline from the estimated bed area in 2020 (Table 1, Figure 3 and Figure 4). Due to conditions at Fenham Flats at the time of the survey, arising from a low-pressure weather system in the area at the time, not all areas of the bed were accessible due to higher water levels than expected. As a result of this, there is reduced confidence in the bed area estimated in 2023, which is thought to be overestimated by approximately 11.4ha. Whilst there has been a slight decline in bed area since 2020, estimated bed area has fluctuated since surveys began.

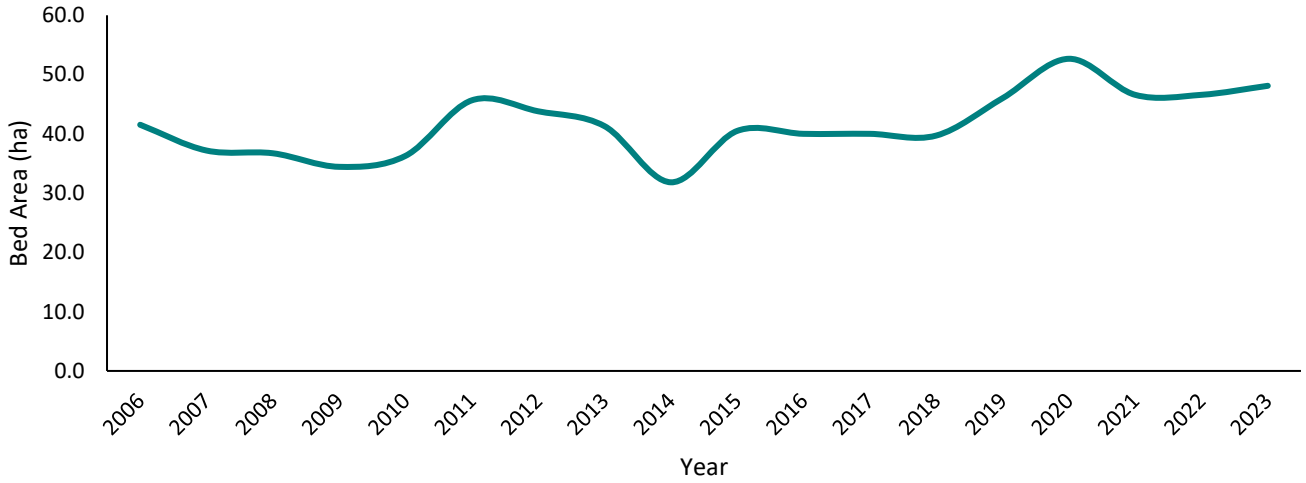

Figure 3: Bed area estimates for Fenham Flats 2006-2023.

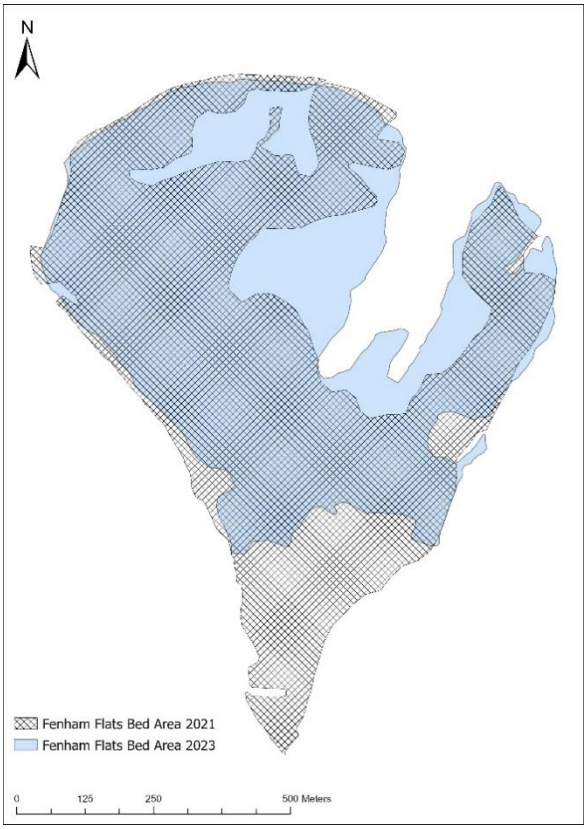

Figure 4: Bed area estimate for 2023 overlayed with the recorded area for the Fenham Flats mussel bed in 2021.

Percentage Cover

In 2023, percentage cover across the mussel bed varied from 0-9% (Table 2, Figure 5, Figure 6 and Figure 7). For the calculation of the mussel bed mean percentage cover, 3 transects were removed from the analysis because they fell outside of estimated bed area (Table 2). Of the transects removed, 2 were partially outside, and 1 entirely outside of the estimated bed area. For the transects for the 2023 survey, previous transects carried out in 2022 were used as a guide to inform the 2023 survey. As a result of a change in the shape of the bed area in 2023 compared to 2021 (Figure 4), the aforementioned transects fell outside of the current estimated bed area in 2023.

Table 2: Percentage cover estimates from transects across the Fenham Flats mussel bed in 2023, highlighting the transects removed from the analysis and percentage cover estimations for the bed.

Transect Number	Percentage Cover	Comments
T1	8%	
T2	3%	
T3	2%	
T4	6%	
T5	3%	
T6	3%	
T7	3%	
T8	4%	
T9	3%	
T10	3%	
T11	7%	
T12	2%	
T13	7%	
T14	2%	Removed from analysis, partially outside of bed.
T15	0%	Removed from analysis, outside of bed.
T16	1%	Removed from analysis, partially outside of bed.
T17	9%	

In 2023, average percentage cover was calculated as 4.37%, falling from 17.39% in 2022 (Figure 5). Estimates have fluctuated annually since 2006 and have displayed a steady decline since 2007, however there has been a significantly increased decline since 2021, where average percentage cover was calculated as 43.47%. Throughout the mussel bed, percentage cover was not distributed evenly (Figure 6 and Figure 7), however there does not appear to be a trend of higher percentage cover in any specific part of the bed area in the 2023 survey.

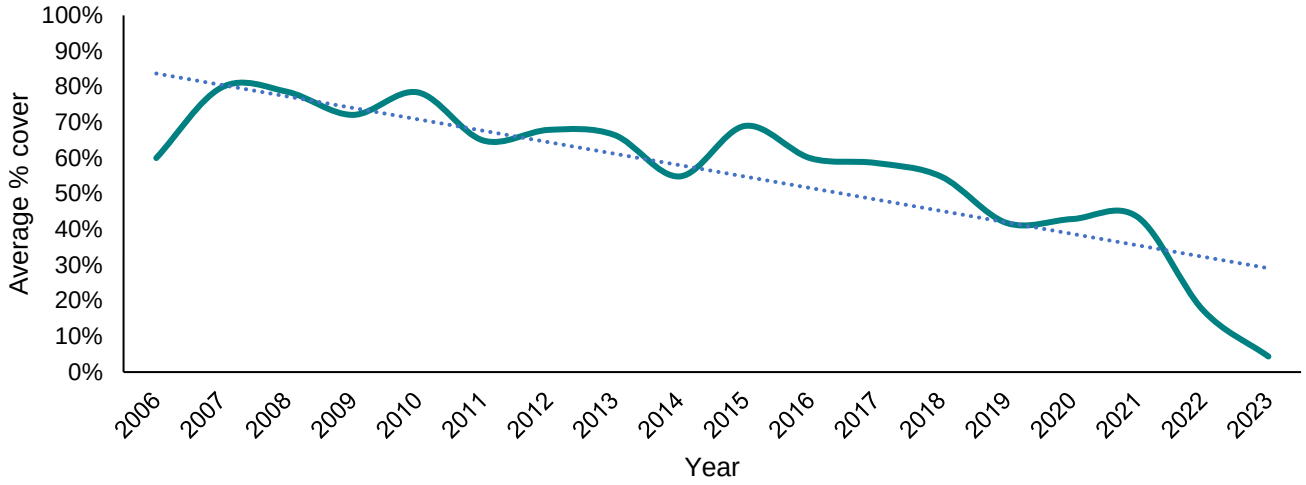

Figure 5: Average percentage cover estimates for Fenham Flats 2006-2023.

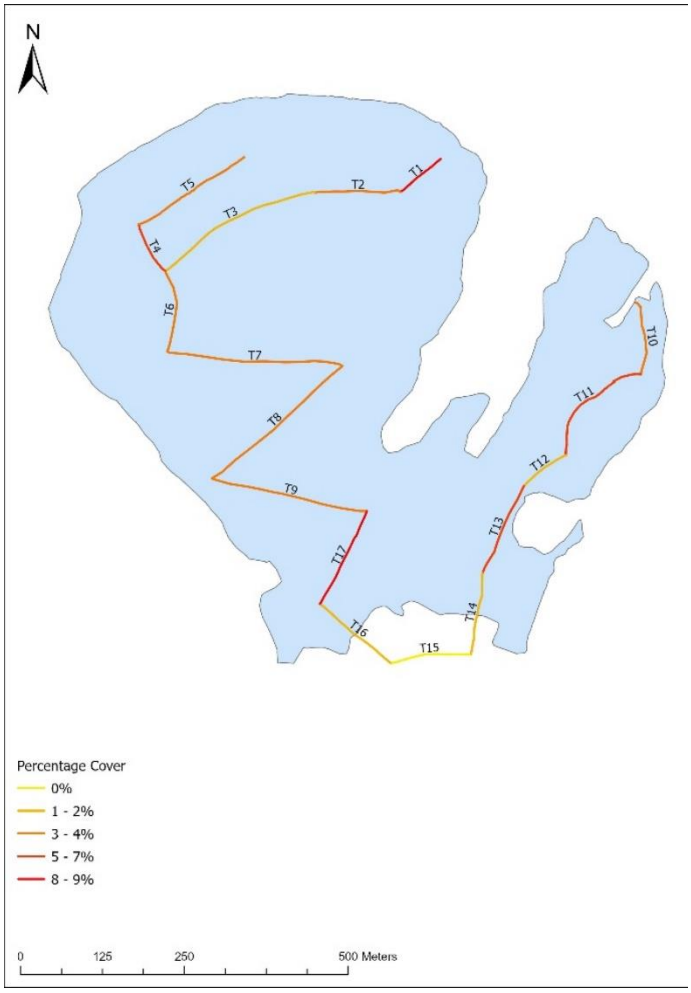

Figure 6: Percentage cover recorded over the transects walked throughout the Fenham Flats mussel bed in 2023.

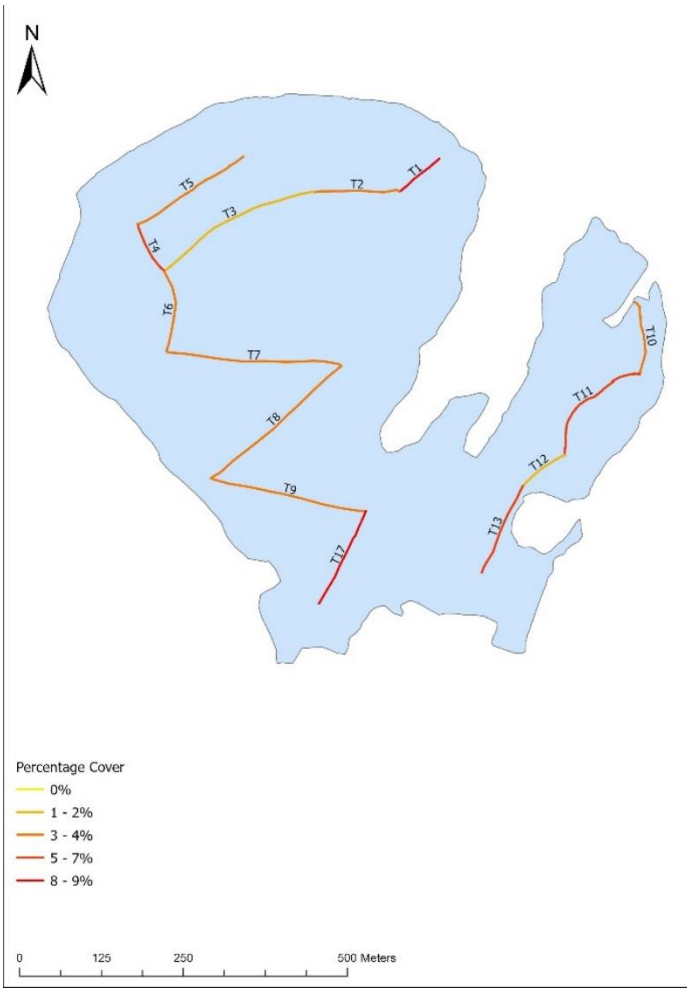

Figure 7: Transects used as part of the analysis of the percentage cover of the Fenham Flats mussel bed in 2023.

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 0.5 mussels/m^2 in 2023 (Figure 8), dropping from 4 mussels/m^2 in 2022. 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 in the following surveys.

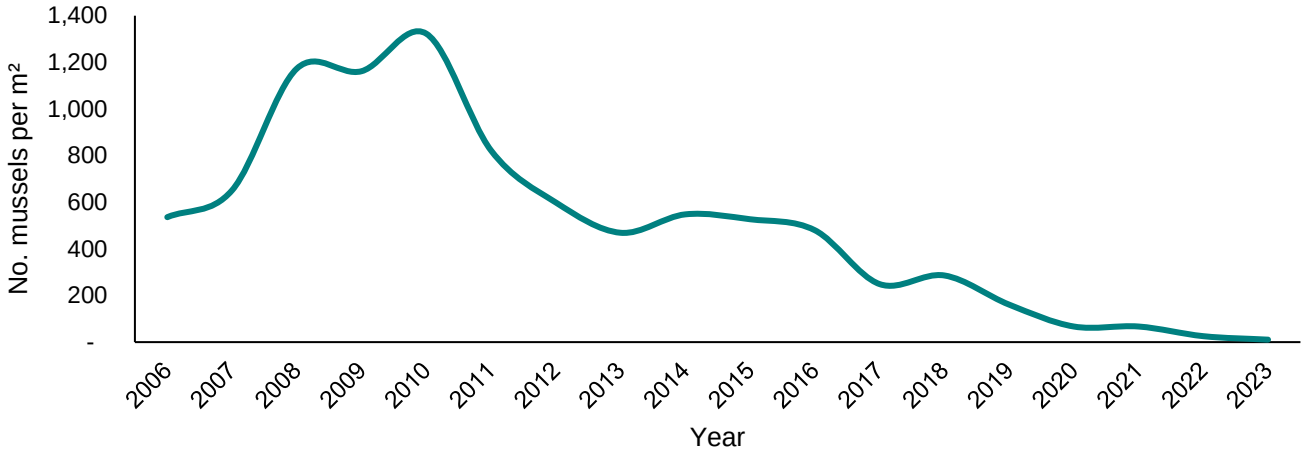

Figure 8: Mussel density estimates for Fenham Flats 2006-2023.

Length Frequency

Despite the survey commencing in 2006, length frequency data was only available from 2013. In 2023, 19 mussels were sampled from 18 sampling stations. Two of the sampling stations fell outside of the mussel bed, and therefore no mussels were found in these samples. It is difficult to determine how the population is distributed given the lack of data in 2023, however it does appear to conform to the bimodal distribution observed in previous years (Figure 9 and Figure 10), although there is lower confidence in this given the sample size. In 2023, there continued to be a higher proportion of individuals in the samples in the <45mm category, as was observed in 2022 (Figure 10). The percentage of mussels within the sample that measured <45mm, was 37%, similar to the 33% recorded in 2022 (Figure 11). Despite this, the >54mm category was still the most dominant in the samples from 2023, accounting for 53% of the mussels sampled (Figure 11). 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, although the most densely populated areas were generally in the north of the bed (Figure 12).

Mean shell length increased from 47.35mm in 2022 to 48.32mm in 2023, as a result of the larger proportion of mussels sampled in the >54mm size class, continuing a trend of increasing mean mussel size (Figure 13). There was an increase in the number of smaller individuals recorded in samples in 2021, therefore mean shell length decreased.

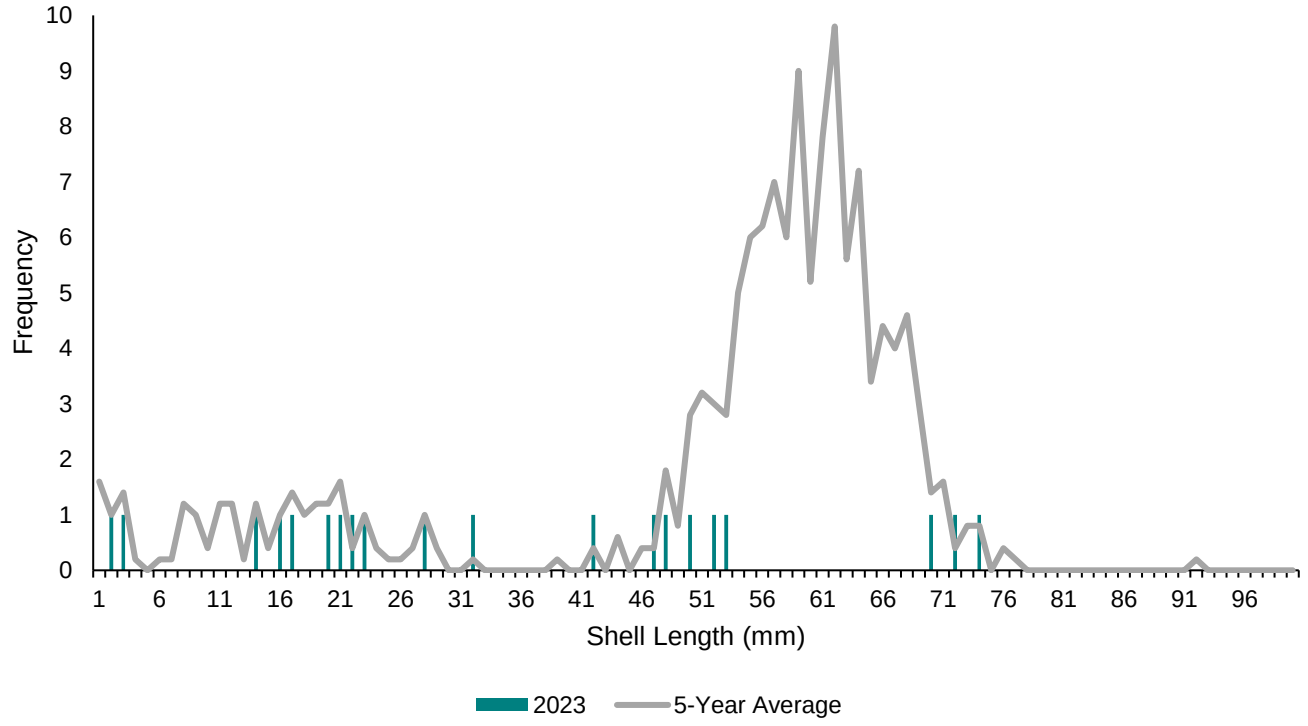

Figure 9: Length frequency (number of individuals in each mm size class) for mussels sampled in the 2023 survey of Fenham Flats, as well as the 5-year average frequency for the mussel bed.

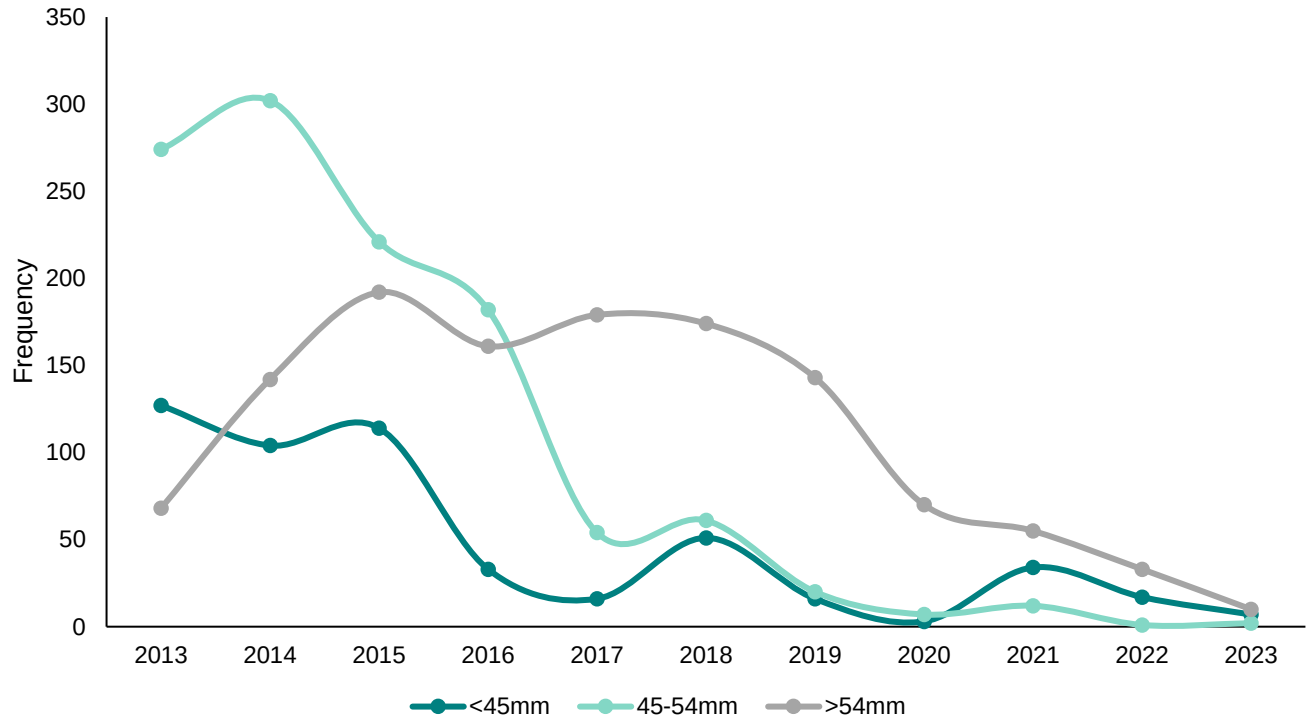

Figure 10: Frequency of sampled mussels between 2013 and 2023 for the <45mm, 45-50mm and 50mm size classes.

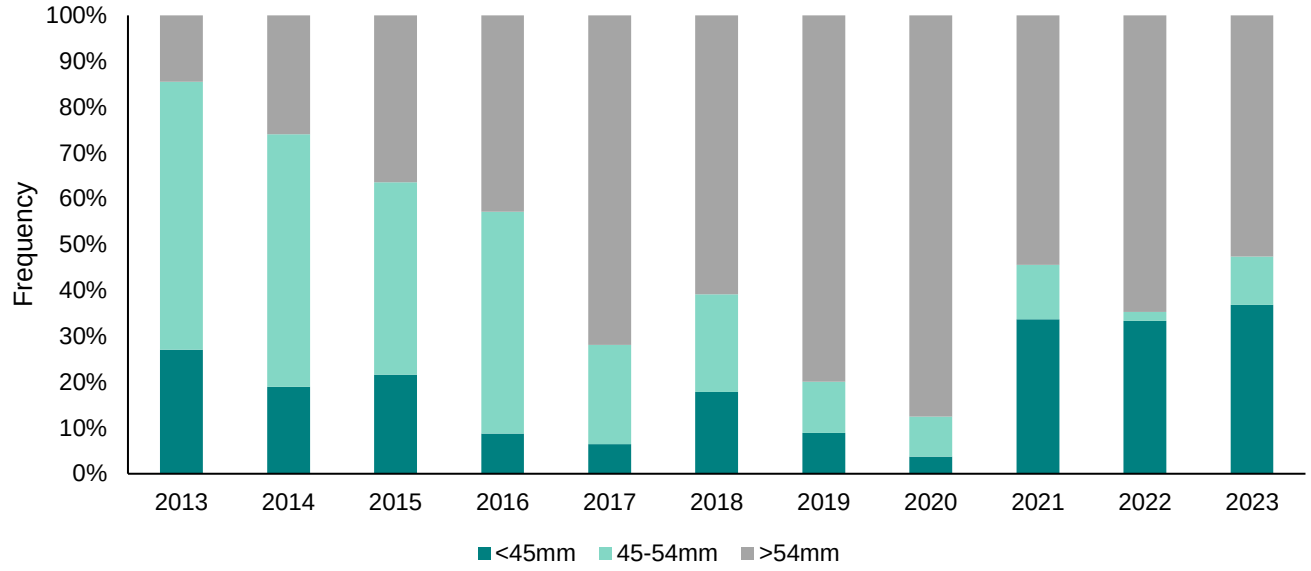

Figure 11: Proportional percentages of sampled mussels between 2013 and 2023 for the <45mm, 45-50mm and >50mm size classes.

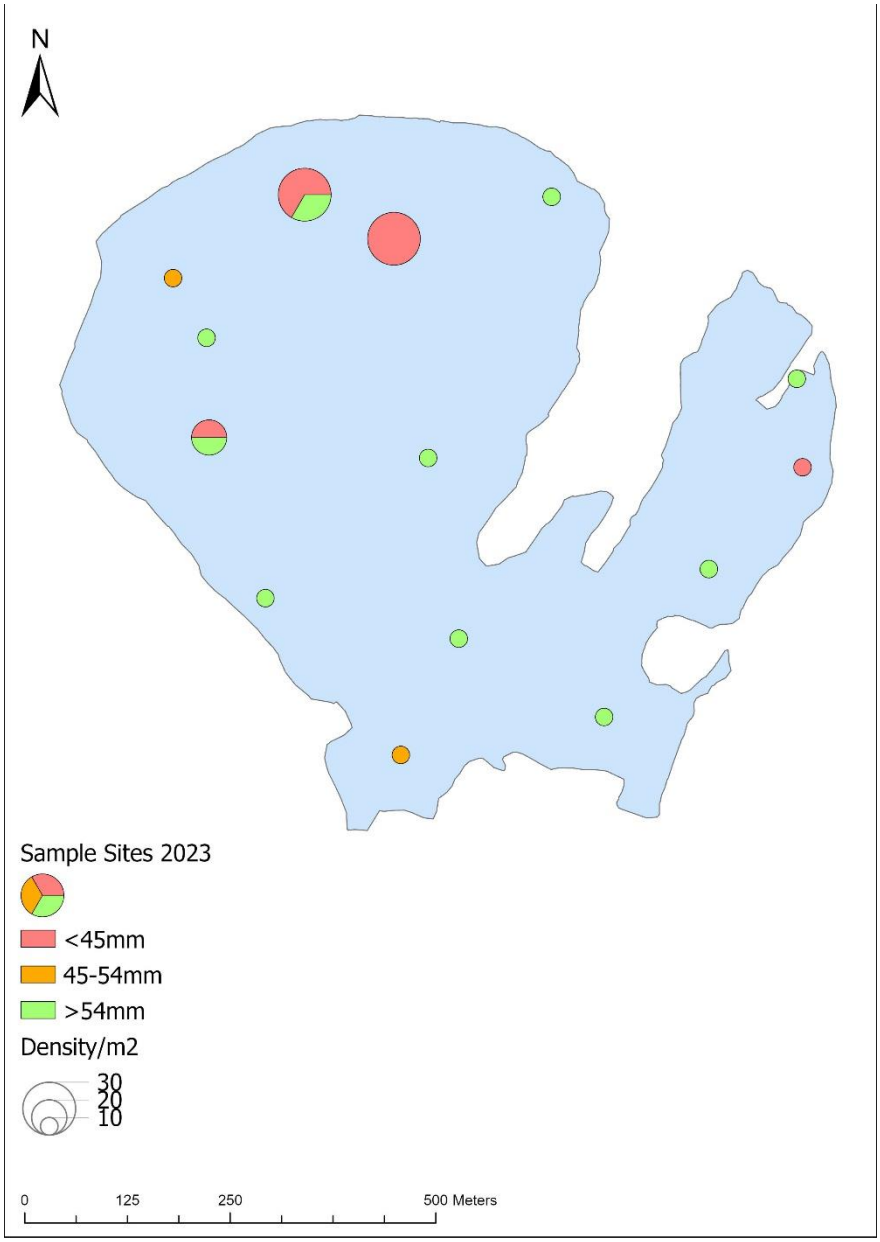

Figure 12: A breakdown for individual sample sites and the proportional percentages of the <45mm, 45-50mm and 50mm size classes. These points have also been proportionately scaled by the number of individuals recorded at each sample site, with sites containing larger sample numbers being displayed larger on the map. The bed area shown is the mussel bed calculated in 2023, with the 2023 sample sites plotted over it.

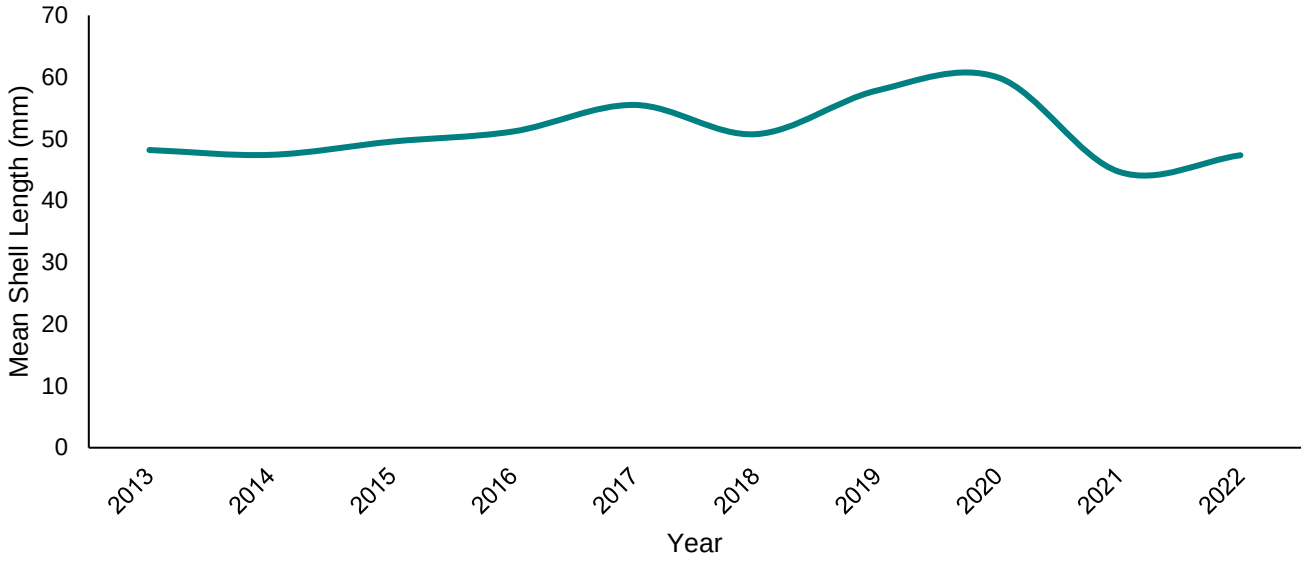

Figure 13: Mean mussel length for Fenham Flats 2013-2022.

Mussel Stock

Due to low pressure conditions meaning not all areas of the bed being accessible, there is a lower confidence in the mussel stock analysis for 2023. Despite this, is it does appear that the bed has continued the trend of mussel stock decline. Total numbers of mussels at the site fell from 2.1 million in 2022 to 0.2 million in 2023, with total biomass following a similar trend, falling from 70 tonnes in 2022, to 9 tonnes in 2023 (Figure 14). Overall, since 2006 there has been a significant decline in both biomass and the number of mussels, with a decline of around 99.81% in the total number of mussels from 2006-2023 (Figure 14).

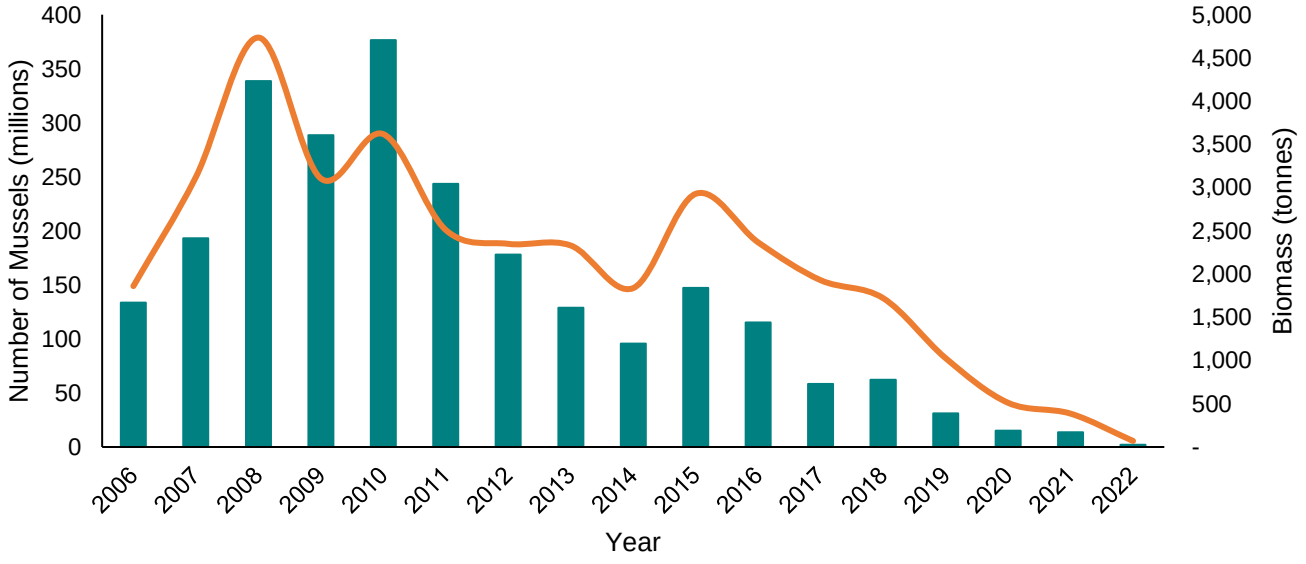

Figure 14: Mussel quantity and biomass estimates for Fenham Flats 2006-2022.

Discussion

Bed Area

Due to weather conditions at the time and a higher tide than expected, the mussel bed was not accurately mapped in 2023 and likely some of the extent has been lost as a result, as has the overall accuracy due to inaccessibility to certain areas of the bed. It should be noted that the southern-most extent of the bed recorded in 2021, was accessible in 2023, but not included in the bed area calculations for 2023 due to no mussels found in this area in 2023. This is a significant change to the overall bed area and will be monitored in future years. 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. Further monitoring of environmental conditions, namely weather and pressure systems will be carried out closer to the time of the survey to determine the suitability of those conditions for accurate bed area calculations.

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 since 2015, with a significant decrease between 2021 and 2022, continuing into 2023.Throughout the site, percentage cover was variable, with transects carried out in the centre of the bed area higher than those on the fringes. 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. Percentage cover estimates do not rely upon bed area to be calculated, there is more confidence is these 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 (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 and 2023, with significant declines over this period. 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). However, the large number of small individuals of mussels found in the surveys from 2021 onwards does seem to suggest recruitment at the site. The population of *M. gigas* at the local aquaculture setup has anecdotally been reported as doing very 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, as well as NIFCA survey data, 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 (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

In 2023, length frequency demonstrated a bimodal distribution, which was also reported in 2022, 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. This sort of feeding behaviour would explain the lack of mussels at the site from 45-54mm in length. 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 issues relating to the calculation of the bed area for 2023 makes analysis of the mussel stock with any significant confidence difficult. Despite this, it is possible to reasonably infer from the data that there has been a decline in the mussel stock at the site, the true extent of which is at present unknown without a more accurate bed area estimate for 2023. 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 confidence in the 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 recent years 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. What is clear is that the overall number of mussels at the site, regardless of size, have declined across the board.

The biomass estimates per m^2 in 2023 can however be relied upon, as this does not factor in the bed area when it is calculated. There was an alarming drop in the biomass estimates for 2023 when compared to 2021, falling by 98%. Results from 2023 continue the declining trend recorded over the past 13 years. The mussel bed at Fenham Flats is at risk of disappearing further research is urgently needed to identify and address the cause, or causes, of the decline.

As a result of the declines observed at Fenham Flats, surveys were undertaken at Holy Island Sands in 2018 as a comparative survey to determine the health of mussels on the Holy Island Sands bed. If mussels at Holy Island Sands were found to be healthy while Fenham Flats continued to decline, causes of decline at Fenham Flats could be narrowed down to very localised issues. However, the declines recorded at Holy Island Sands, plus the declines reported elsewhere in the UK suggest the cause(s) of decline are more far reaching and widespread.

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 by 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. Initial results were promising and could indicate mussel bed extent through multispectoral analysis. Despite this, it is not feasible for NIFCA to survey this mussel bed using a drone, as the height the drone is required to fly at to accurately map out the mussel bed is impractical and would take too much time to map out the bed area with any degree of accuracy.

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 2023 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. Determining the cause, or causes, of this decline is a key focus of future work. 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, and;
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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