Natural England Research Report RR04412

Human impacts on Cromer Shoal Chalk Beds MCZ: Chalk complexity and population dynamics of commercial crustaceans

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Executive Summary

The Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ) abuts the North Norfolk Coast and is one of the most ecologically significant Marine Protected Areas for chalk habitats in the UK and Europe. Chalk is particularly important because of its scarcity and the distinct communities that it supports. This includes a nationally significant crab and lobster industry worth an average £2.4million a year and it is crucial to the heritage, character and economy of the North Norfolk Coast. In 2018 Natural England received new evidence that crab and lobster potting was impacting the physical structure of the chalk bed, an internationally rare habitat. Natural England needed to provide statutory advice to the Eastern Inshore Fisheries and Conservation Authority (EIFCA) on their fisheries management in the MCZ and the significance of this damage.

During 2019 Natural England, in partnership with others including EIFCA and University of Essex collected further evidence on the impact of the potting fishery on the chalk bed and the levels of fishing activity for the following purposes: to provide clear and proportionate statutory advice to EIFCA in 2020; to enable the fishers to see and understand their impact and to suggest mitigation measures; and finally to provide an opportunity to promote the importance of the chalk bed and marine environment more widely using novel three dimensional photogrammetry (3DPG) modelling techniques.

In September 2019 Natural England undertook a dive survey with the University of Essex. The aim was to investigate human impacts on Cromer shoal chalk and the relationship between chalk complexity and population dynamics of commercial crustaceans. In addition to the investigation of human-attributed damage to the chalk bed, we trialled techniques using 3D photogrammetry modelling from video footage as a proof of concept for future studies where analysis of structural features in an environment need to be collected quickly and analysed in detail.

The results show that adult crabs (*C. pagurus*) were found in areas of higher complexity on the chalk bed; however, juveniles can be found in all areas. There were not enough observations of lobsters (*H. gammarus*) to identify patterns in their distribution, and further study is required for this species.

Eleven types of damage were categorised and observed on the chalk bed during four dives. The chalk bed had numerous occurrences of impact in comparison to a flint cobble plain in the MCZ which had no occurrences of impact. West Sheringham and West Runton chalk sites showed similar damage characteristics: abrasion with some shears and strike damage. East Runton on the other hand had a high occurrence of rubble, strikes and unlevel shears, and comparatively less abrasions.

The severity of damage was different across the sites, with the West Sheringham chalk site most impacted by severe types of human-attributed damage. Pots, anchors and ropes cause low to high severity types of damage to the chalk bed but some categories are not all attributed to human activity. Natural damage is considered a factor, but the human attributed damage is additive.

A larger scale study is required to better understand the scale, frequency and causes of the damage observed. This should be part of an adaptive risk management approach informed by an assessment of the activity in relation to the conservation objectives of the site. We

hope the output of this investigation will support a dialogue between stakeholders in the sustainable management of the Cromer Shoal Chalk Beds MCZ and other MPAs designated for chalk habitats elsewhere

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1 Introduction

1.1 Cromer Shoal Chalk Beds MCZ

Cromer Shoal Chalk Beds MCZ (CSCB MCZ, Figure 1) was designated in 2016 as part of Tranche 2 of the MCZ designation process under the Marine and Coastal Access Act (MCAA) 2009 (UK Parliament, 2016).

The MCZ was designated for ten chalk, rocky, sedimentary habitats and a geological feature in an area of predominantly sandy seabed (See Appendix I for a full list of features and site description). The conservation objectives for those features were set as 'maintain' based on best available evidence at the time. This evidence consisted of professional and citizen science surveys as well as assessments on sensitivity and risk of features from activities known to take place within or near to the MCZ based on expert judgement. These activities included offshore wind farms, coastal defence works and fishing, both recreational and commercial.

Chalk is a sedimentary rock that was deposited in the Late Cretaceous period largely comprising calcareous skeletons from dead planktonic organisms e.g. coccolithophores (UCL 2018). Marine chalk is a scarce resource in Europe and worldwide, with c.57% of the European resource being located on the coast of Britain with only 0.6% of the British coastline formed of chalk according to JNCC (2011) and Tittley (2009). England therefore has an international responsibility to ensure the conservation of marine chalk habitats for their scarcity and ecological significance due to the distinct communities they support (Fowler & Tittley 1993).

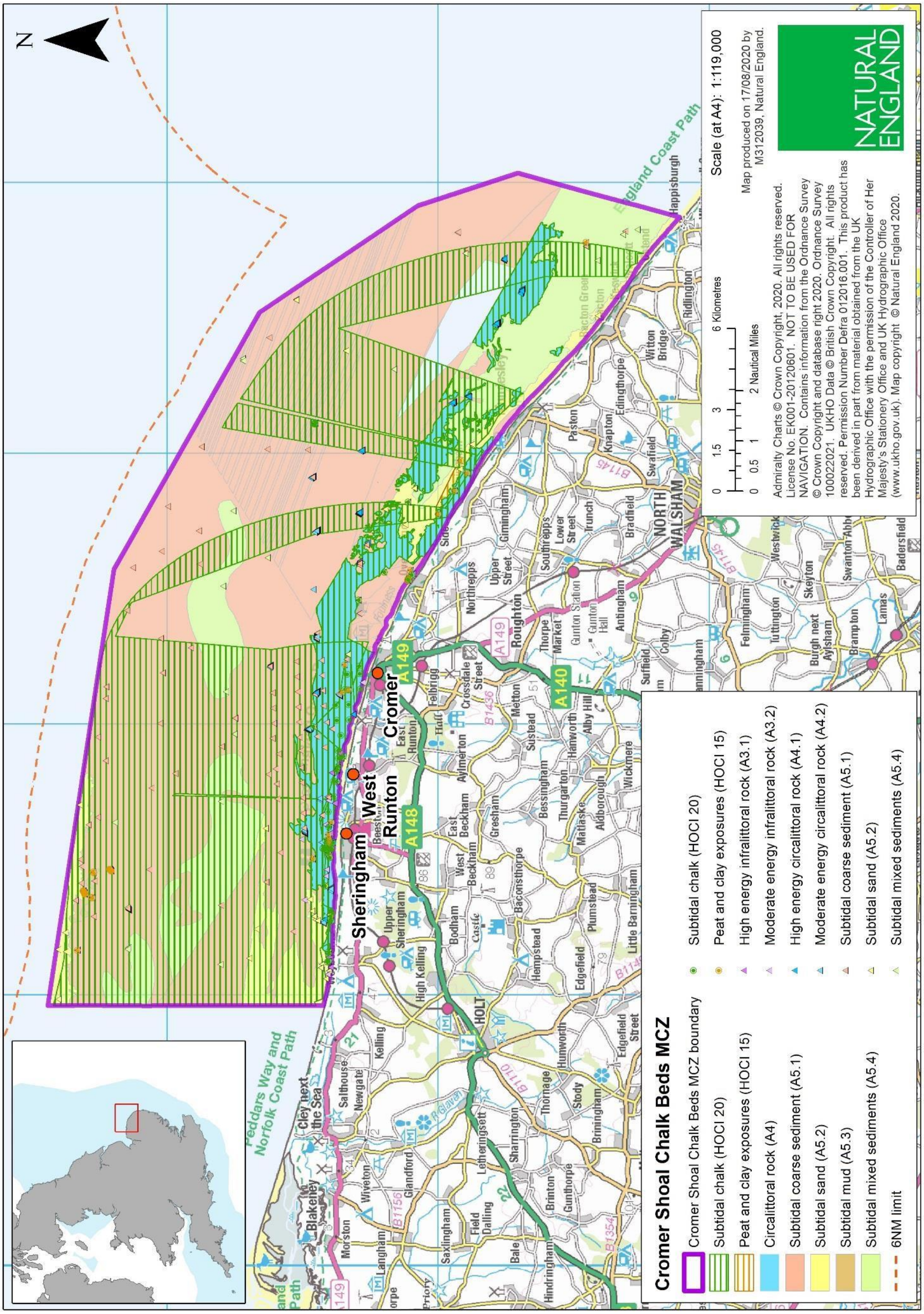
Subtidal chalk is a feature of conservation importance (FOCI) under the MCAA 2009. Chalk may also be protected in MCZs as broad-scale habitats. These include high energy infralittoral rock, moderate energy infralittoral rock, high energy circalittoral rock and moderate energy circalittoral rock amongst others, all of which are found at CSCB MCZ.

CSCB MCZ extends from Weybourne to Happisburgh, from 200m seaward of Mean Low Water (MLW) to between five and 10km offshore, enclosing an area of 321kmsq. Some of the best examples of subtidal chalk beds in Europe are found in the form of flat plains, ridges, gullies and undulations of chalk. The site gradually slopes from Lowest Astronomical Tide to 27m depth at the outer border of the site (Green 2015).

A large area of infralittoral rock extends across the site from east to west, but it generally occupies shallow inshore waters (up to 10m depth). This wide expanse of stable substrate provides a suitable habitat for sessile and mobile epifauna where gravel interspersed with fine sediments mostly dominate. Beyond the infralittoral rock there is a band of circalittoral rock with more epifauna and less light penetration, resulting in less macroalgae (Green 2015). Infralittoral and circalittoral rock within the site are comprised of subtidal chalk, along with other rock types. As it isn't possible to accurately differentiate between different types of rock from geophysical survey data, areas mapped as the subtidal chalk feature will overlap with areas mapped as circalittoral and infralittoral rock features.

From Sheringham, East and West Runton, to Cromer, subtidal chalk occurs from quite close to the intertidal zone to well offshore. However in the southeast portion, towards Sea Palling, the chalk is predominantly offshore, with limited presence inshore. Here, the inshore chalk is replaced by subtidal sand and subtidal mixed sediments and further offshore, beyond the chalk beds, the site is dominated by subtidal coarse sediments. There is also a thin band of subtidal mixed sediments running from east to west. In the northwest portion, coarse sediments transition to finer material, mixing with subtidal mud and sand.

Figure 1: Cromer Shoal Chalk Beds MCZ Designation map



Along the outer border of the site in deeper water, isolated outcrops of clay occur. However, it should be noted the southern North Sea is a very dynamic environment with vast quantities of sediment constantly moved by tides and currents so there is frequent change in substrate and rock distributions. New areas of chalk may become exposed and others become covered by sediment when there are tidal surges or storms (JNCC 2004).

There have been blue mussel beds and large populations of the Ross worm, *Sabellaria spinulosa* confirmed at numerous locations in the east of the site (Green 2015).

The complexities of reef systems provide a vital ecosystem for many marine organisms. Though reef commonly refers to coral reef environments, chalk deposition over geological time from calcite shells can build up into massive stretches of chalk reef in all manner of scales and shapes. The rugged and complex structures formed by the chalk bed provide habitat variations that allow for a wide range of organisms to thrive, allowing for refuge from predation and for spawning, grazing and hunting grounds and a range of environmental conditions that suit different environmental niches. The complexity of chalk bed is due to the interaction between the relatively soft and layered structure with the erosive effects of the local environment. Of all the organisms supported by and reliant on chalk reefs, crustaceans are some of the most utilised by humans. The target species for these fisheries, the edible crab *Cancer pagurus* and lobster *Homarus gammarus*, are common along many coastlines. In Norfolk they are fished seasonally, with *C. pagurus* potted from late spring to early autumn and *H. gammarus* from early summer through to mid-autumn, although the season is variable.

1.2 Marine Conservation Zones (MCZ)

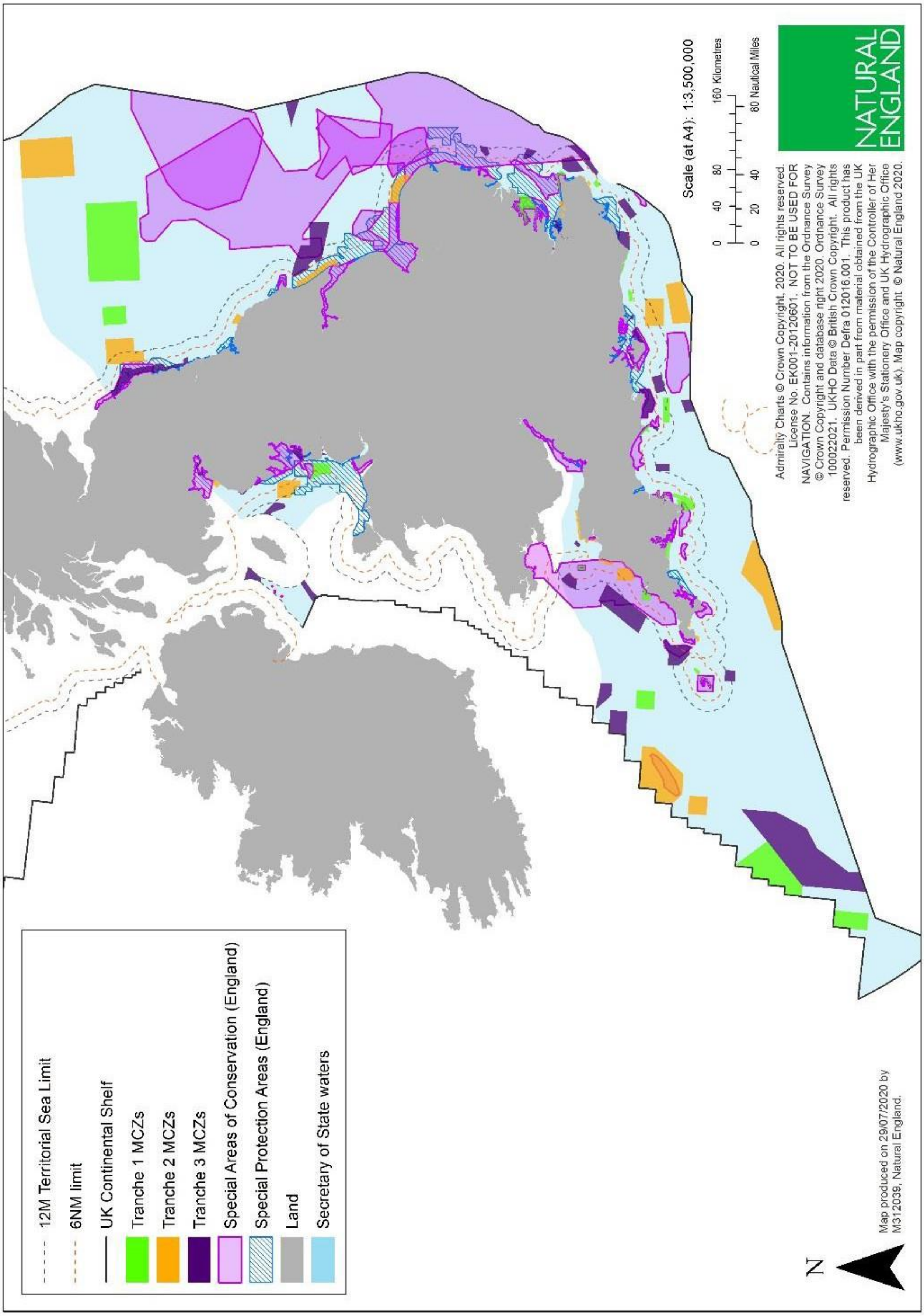
Marine Conservation Zones were designated to protect rare, threatened and representative habitats, species and geological features of national importance and came in to being under the Marine and Coastal Access Act of 2009. The aim was to create a well-managed, ecologically coherent network of Marine Protected Areas in English waters to promote clean, healthy and biologically diverse oceans and seas.

The MCZ Project took ten years and led to the designation of 91 MCZs in three tranches incorporating broadscale habitats (BSH), habitats of conservation importance (HOCI) and species of conservation importance (SOCI), some of which were mobile. Added to that additional Special Areas of Conservation (SACs), Special Protected Areas (SPA), Ramsar sites and Sites of Special Scientific Interest, there is now significant progress to achieving this ecological network.

To date there are 177 Marine Protected Areas (MPAs) in English waters (Figure 2) covering an area of 92 300 km2 or 9.2million ha which constitutes 40% English Waters (Burney 2020. Natural England Marine Conference). It’s important to note there are more SPAs to follow.

One important key difference with the Marine Conservation Zone project compared to other MPA designations was that not only did project managers and decision makers look at the ecological benefits and impacts of designation, but socio-economic impacts were considered too. Seabed users and local communities were a key part of the designation process and there was significant public consultation before final decisions were made by Ministers**.**

Figure 2. Marine Protected Area Network currently designated in English Waters



MPAs have defined boundaries managed, through legal or other effective means for conservation of their features in the long term. The UK Government is committed to creating an ecologically coherent network of MPAs under the Convention on Biological Diversity and the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR convention) This convention aims to enable the network to jointly provide greater environmental benefits than a single site could on its own (Moffat and others 2020).

In MPAs where chalk is a protected feature under any UK or European legislation, the feature will come with associated conservation advice and conservation objectives. These aim to provide information on the activities that may impact the features and the processes they depend on. The conservation objectives for a site state that subject to natural change, the protected features should be maintained, or restored where necessary, to favourable condition. It is these objectives that the condition of the site will be assessed against.

1.3 Cromer Shoal Chalk Beds Fishery

Crustacean shellfisheries are hugely important in North Norfolk. They are fundamental to the heritage, character and economy of the North Norfolk coast and have been sustained since the mid-18th Century. However, Daniel Defoe mentioned Norfolk's sea fare back in 1724 so in reality the fishery has been around much longer. In 1875 it was estimated there were 200 fishermen with 100 crab boats in Sheringham and 50 in Cromer. In 2013 it was estimated there were 48 boats in the whole fishery with 75 fishermen associated in the whole of the North Norfolk coast from Wells to Sea Palling (White 2015)**.** In 2014 there were 17 full-time boats employing 20 fishers from Cromer with 5 or 6 part time boats from Sheringham (White 2015). The reasons for this decline are not only the lower catches but also the increased regulatory framework of the fishery becoming more restrictive, making the fishery more difficult and expensive (White 2015).

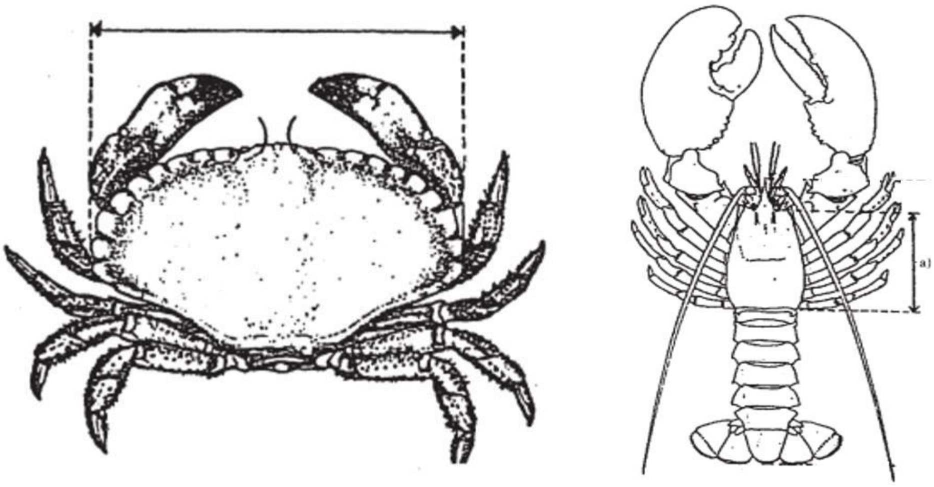
The crustacean shellfisheries are comprised of brown crab, *Cancer pagurus,* from which the famous Cromer Crab name comes from and also European lobster, *Homarus gammarus* (Figure 3). Whelks, *Buccinum undatum* do also form part of this fishery, but are less intensive and primarily supply the South Korean market. Most of the vessels operating on the North Norfolk Coast are in the less than 10m in length category and historically operated within 2nm of the shore (Bridges 2017). Gear advancements have led to increases in operational range, but the smaller vessels still tend to keep inshore with the larger ones going further afield (Bridges 2017).

From the under 10m fleet, monthly shellfish activity returns (MSAR) collated from 2006-2017 for combined target species catches were an average of 736 tonnes (t) per annum. From 2014-2016 they were over 1000 t per annum on average. After 2016 combined landings decreased significantly to just over 770 t for 2017 but this was matched with a reduced effort. Crab landings accounted for most of this and lobsters accounted for less than a quarter. The significant decrease in 2017; believed to have been due to the increased numbers landed in previous years (Bridges, 2017) was an all-time low. In 2014-2016 values were £1.4-1.9 million for the brown crab alone, however in 2017 it plummeted to £0.6 million and £0.7 million for lobsters. From further stock assessments completed annually by EIFCA there was acknowledgement that crabs are being fished just beyond their maximum sustainable yield (MSY) by Bridges (2017). EIFCA consulted with stakeholders on potential management in 2019 on this issue. Average mean values of crab and lobster during this period (2006-2017) indicate the mean combined fishery is worth £2.3 million. The value of the European lobster fishery conversely has remained stable in landings and effort so this fishery is a steady economy for North Norfolk fishers (Bridge 2017). The social and cultural importance of artisanal fisheries are recognised in national and European policy but participation in governance of fishing communities is very limited in general and this hinders sustainable development and social resilience (White 2015).

Figure 3: Commercial crustaceans: (left) Brown or Cromer crab *Cancer pagurus*; and (right) European lobster *Homarus gammarus*.

The minimum landing size of brown crab and European lobster within the EIFCA region is notably smaller than elsewhere in the UK. This is 115mm carapace width for *C. pagurus* and 87mm carapace length for *H. gammarus* (Figure 4).

Figure 4: Measurement of carapace of crab and lobster (EIFCA, 2020).



Population studies have revealed a smaller average size of crab and lobster in North Norfolk when compared to adjacent areas (Welby 2015). It is believed to be because of migration patterns and recruitment regimes in crabs according to Eaton (2003) and a lack of suitable refuges for larger animals in lobsters (Howard 1980). Local fishers state the smaller crabs gives them a much sweeter taste. Why this is, is open to speculation, but according to some they are slower growing and their chalky habitat in shallow water may be a contributing factor.

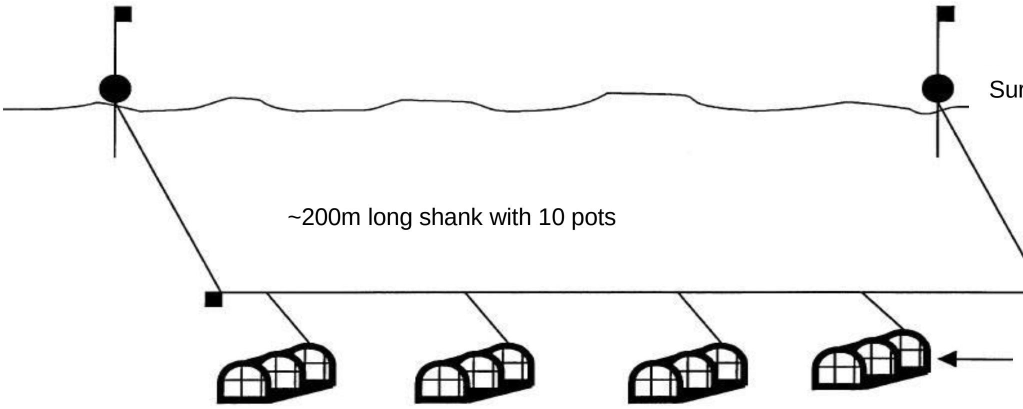
Potting fisheries target crustaceans through the deployment of static gears. These are a string (or shanks) of 20-30 baited pots on tethers 1-3m long, typically left to soak (fishing on the seabed) for 24-48 hours before being retrieved. Several shanks on a rotational basis will be targeted, hauling between 100-500 pots each trip. Use of such static gear has low mortality rates of incidental bycatch compared to other gear types and discard survival rates are high. This enables the non-target individuals to grow to a size where they will recruit to the fishery in the future (Bridges 2017).

There are different types of pots available but the small parlour types pots (Figure 5, right) are observed in North Norfolk and this has remained consistent for generations.

Figure 5: Pot designs include traditional inkwell pots and creels, modern parlour pots and aluminium wire pots (Bridges, 2017).

Configurations of potting methods can vary regionally but off the North Norfolk coast the configuration below (Figure 6) is what has been observed. These pots were largely deployed from vessels less than 10 m long, launched from the beaches using tractors. The vessels are mostly single manned and remain closely inshore in water less than 10m depth.

Figure 6: Pot fishing fleet configuration from Stephenson and others (2018).



Fishers deploy and retrieve pots by hand although sometimes a mechanical hauler is used. Catches are then sorted at sea disposing of undersized or poor-quality crustaceans before redeploying once more. Fishers then return to shore to process and sell their catch.

Some areas of the UK have seen increases in commercial potting activity and the number of UK potting vessels in inshore waters (Mangi and others 2011; Newman and others 2012; Cefas 2014, Öndes 2017) This primary fishing method has intensified with the use of mechanical haulers strengthening commercial pot landings over the past 25 years (Munro and others 2012). Further restrictions on bottom towed fishing gear have led to an escalation in potting (Mangi and others 2011). It is anticipated that potting fisheries could increase further particularly in the quantity of pots and the number of vessels before the impacts of current levels are fully understood (Rees and others 2018).

1.4 Cromer Shoal Chalk Beds MCZ Fisheries Management

Fisheries management in CSCB MCZ is the responsibility of EIFCA. Other activities are managed through the marine licencing process by the Marine Management Organisation (MMO) e.g. port and harbour developments or offshore windfarms (OWF). However there are some non-licensable activities that are not managed but all these activities need to be considered alone and in-combination when assessing impacts on CSCB MCZ including fisheries.

Section 125 of the Marine and Coastal Access Act (MCAA) 2009 applies to any public authority undertaking their duties where these may significantly impact the protected features of an MCZ, and/or the ecological or geomorphological processes on which the conservation of any protected features is dependent. Under this section, public authorities must exercise their functions to further the conservation objectives of the MCZ, and where it is not possible to further these objectives, must carry out activities in the manner that least hinders the achievement of these objectives. To do this, public authorities complete an MCZ assessment.

Section 126 of the MCAA applies where a public authority is giving an authorisation for undertaking an activity. Where the authority believes there is, or may be, a significant risk a proposal will hinder the achievement of the conservation objectives of the MCZ, the authority may not grant authorisation for the activity unless:

a) there are no other alternative methods that would lower the risk;

b) the benefit to the public of proceeding outweighs the risk of damage to the environment that will be created; and

c) the person undertaking the project will put in place measures of equivalent environmental benefit to the damage that will occur within the MCZ. (Marine and Coastal Access Act 2009).

Under Section 40 (S40) of the Natural Environment and Rural Communities (NERC) Act 2006, '*The public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity'*. Section 41, Habitats of Principle Importance for the purpose of conserving biodiversity in England (S41), provides a list of habitats and species of principle importance, which is used to guide decision-makers, in implementing their S40 duty. The list is reviewed by the Secretary of State, in consultation with Natural England, and currently intertidal chalk and subtidal chalk are detailed as Habitats of Principle Importance (HPI). This means that decision-makers must give regard to intertidal and subtidal chalk habitats whenever they are present, even if they are not included within a protected site (NERC Act 2006).

EIFCA began the process of doing their Fisheries Assessment in Cromer Shoal Chalk Beds MCZ in 2018 in consultation with Natural England and the fishing industry. This is an iterative process that may lead to management within the site being proposed for bottom towed gear. Potting, however, was considered by Natural England at the time of designation to be selective, small scale and low impact based on the best available evidence at the time.

In December 2018 compelling evidence was submitted to Natural England which suggested damage to areas of elevated chalk bed, possibly caused from rope abrasion and impact strikes. These are both pressures that could be exerted by potting activity, as well as anchoring of boats and recreational fishing. Natural environmental erosion to the chalk bed can also come from storms and tidal movement so it was important to investigate and verify these impacts and gather further evidence.

The aim of this investigation was to improve the understanding of how the chalk bed and the ecosystem it supports can be impacted from marine activities including fishing, and on what scale. The findings, in conjunction with other studies on the extent of fishing pressure in the area, will inform Natural England's advice to EIFCA, so they can implement appropriate and proportionate management measures in consultation with the fishing industry.

Natural England understand natural processes can create new structural features as well as contributing to the loss of habitats and destruction of features such as arches through erosion. However, until this happens, habitats should be protected to ensure they function for as long as possible and to allow the natural succession of geomorphological features (Moffat and others 2019).

Damage made to marine chalk is irreversible; if the physical structure of chalk is altered then it will not recover itself, so potentially rare elements of the habitats may be completely lost from the marine chalk network. This distinguishes marine chalk from many of the habitats in English waters which can recover through natural processes given time and protection. The scarcity of marine chalk habitats combined with high potential for permanent loss of habitat warrants precautionary management across the marine chalk network to prevent permanent losses. This approach to conservation across a network is hugely significant for habitats like marine chalk, where England contains the majority of worldwide resource. Decision makers have responsibility to ensure the diversity of the habitat is conserved effectively (Moffat and others 2019).

1.5 Crustacean fisheries and their impact on the marine environment

Research to date into the impacts of potting on chalk have focused primarily on the impacts on epifauna and biotopes rather than structure of the substrate. This evidence gap needs addressing urgently, especially considering the rarity and fragility of the habitat.

The Matrix of Fisheries Gear Types and European Marine Site Protected Features (MMO 2014) classes towed demersal gear on 'intertidal chalk reef' as a red risk interaction. A red risk interaction means the fishery is not considered to be compatible with the conservation objectives of the feature and that management must be introduced to prevent this interaction. This was in part due to the potential for fishing gear to physically damage the substrate, leading to reduced structural complexity and the loss of habitat for associated dependent species and reduced biodiversity (Roberts and others 2010). BRIG (2018) also confirms that chalk can be soft, friable and easily eroded and therefore subject to physical damage from heavy or intrusive mobile fishing gears. Epifauna can also be damaged and removed according to Roberts and others (2010). Towed demersal gear on 'subtidal bedrock reef including chalk' and 'subtidal cobble and boulder reef' are also classed as a red risk interaction, due in part to the potential for physical damage to the substrate and a reduction in structural complexity as associated boulders and cobbles are moved around (Engel and Kvitek 2008, Freese and others 1999). Kent and Essex IFCA have introduced fisheries management for bottom towed gears in Thanet Coast MCZ and SAC to protect chalk reef as a result of the MMO risk matrix (Kent and Essex IFCA 2017)

There is limited scientific literature regarding the impact of towed fishing gear on chalk reef largely due to avoidance of this substrate during fishing because of damage risk to fishing gear. As chalk reef formation is a geological process any damage done to the chalk has no or low recoverability but it is recognised that chalk is naturally scoured by sand or crumbled by wave action during storms (Roberts and others 2010).

One of the most recent studies by Rees and others (2018) demonstrated some clear results indicating a 'threshold' at which fishing effort begins to be damaging to crustacean populations and the rocky reef environment. The evidence showed lower effort resulted in higher quality catch. The ethos of 'high quality, low volume' fishery in the Lyme Bay Fisheries and Conservation Reserve Voluntary Code of Conduct is supported by the scientific results of this study. According to Rees and others (2018) high densities of pots sustained over three years can damage the seabed ecosystem and reduce quality and quantity of target species catches. The 'threshold' for commercial potting effort is evidence to support management of commercial potting in MPAs to benefit the fishery and the marine environment. Evidence of a potting density and catch quality relationship is pertinent and will encourage buy in from local fishers. In Lyme Bay it's been achieved through a voluntary code of conduct and management which may help mitigate against intensive potting and encourage future sustainability. This is especially important if there is protection against mobile gears as that can encourage static gear increases. This has been observed by Mangi and others (2011) and anecdotally in MPAs according to Burke (2015), therefore proactive management is required.

Stephenson and others (2018) added to the evidence base on potting impacts by investigating long-term impacts of potting on epi-benthos and habitat within Berwickshire and North Northumberland Coast European Marine Site (EMS). They analysed previously collected condition monitoring data from 2002 & 2012 to assess change over time related to potting intensity. Biotope changes were analysed between years and showed no change but there were limitations with this method so they included community composition and diversity changes too. These also showed little evidence of change except for 'Faunal and algal crusts on exposed to moderately wave exposed circalittoral rock' which did show some change between years but just highlighted the need for further research. However using novel acoustic telemetry methods they did observe pot movements that showed likely direct impacts in different weather conditions. This focussed mainly on the epi-benthos and showed little impact in UK waters. There were some impacts evident in US waters with coral and sponge species which did increase with reduced water depth. Depth plays a key role in the magnitude of that impact, but it does highlight there is limited applicability to UK shellfisheries as the methods are different. The study was unable to recommend maximum potting levels that sessile epifauna can withstand at a site and does highlight the cumulative impacts from repeat fishing are not well understood and further site-specific studies are needed to determine optimum fishing levels to benefit the fishery and conservation interests (Eno and others 2001).

Significant pot movements did not occur every day in the Northumberland study but were detected on just under one third of the sampling occasions. Movement occurred with swell heights of 0-1 m and more than 2 m, but not 1-2 m swells and both neap and spring tides produced significant movements, indicating that even weak weather events may cause underwater pot movement. Two thirds of the sampling days with significant pot movement occurred during spring tides. Pots that experienced significant movement did so mostly along a North-South axis which indicates the North-South flood and ebb tides and large ground swell could be affecting pot movement (Stephenson 2018). This could well be the case in North Norfolk too but further study is required for more validation. Pot movement is not a daily occurrence according to Stephenson and others (2018) but significant movement was recorded on less than half of the sampling days. Further work is required to confirm this as there are limitations with the data and ability to make comparisons. Stephenson and others (2018) states movement may be influenced by a complex interaction of environmental variables not quantified in their research.

Walmsely and others (2015) stated that individual species that bore into chalk, such as piddocks, are predicted to be relatively unaffected by static gears that do not damage the reef. Cumulative damage over time could be caused by the setting of the pots and their ground lines and anchors and their movement over the bottom during rough, stormy weather. Differences in community assemblages between potted and unfished areas were evident on chalk reef in the Flamborough Head European Marine Site (EMS) when survey data and vulnerability assessments were analysed. They suggested the levels of potting were impacting on the benthic conservation features *Sacharina latissima* as it is intolerant to physical abrasion but does have a high recoverability. Settlement potential is expected to be hindered by consistently high levels of potting. Bryozoan abundance showed similarities between sites suggesting less sensitivity to potting pressure.

Walmsely and others (2015) concluded there were few primary evidence sources that address the physical impacts of potting on benthic ecology. Some studies found no or limited significant impacts of potting but all the studies had limitations. There were differences in community assemblages between potted and unfished areas on subtidal chalk reef according to Young (2013), but there was variable visibility between the two comparison sites. In conclusion, it is evident there are still large knowledge gaps to be addressed to inform appropriate and proportionate advice from Natural England based on the best available evidence. This report will fill some of those gaps but further study is needed.

1.6 Research questions

We hypothesise that some areas of the chalk bed provide higher productivity (defined as abundance of commercial crustaceans) due to high complexity of features providing refuge for large, productive individuals. Due to the territorial nature of crustaceans, many juveniles will be forced out of these areas and move along the reef to find refuge in other areas. Specifically:

> *RQ1 Areas containing large, complex chalk features will have a higher abundance of adult commercial crustaceans than the flatter areas of chalk bedrock.*
>
> *RQ2 Juvenile commercial crustacean density will be similar across all chalk areas.*

Additionally, we hypothesise that chalk bed areas of high rugosity and complexity are more vulnerable to human impacts due to the soft composition of the substrate, thus:

> *RQ3 Areas with large, complex chalk features will show evidence of more impact than the flatter areas of chalk bedrock.*

2 Method

The North Norfolk chalk bed extends from the intertidal to the north in increasingly isolated ridges and channels, spanning from Weybourne to Happisburgh, parallel to the coastline. Areas of varied chalk bed were investigated between Sheringham and West Runton and active shanks of pots within each area were randomly chosen. Precise GPS locations of the areas investigated will not be made public to protect commercial sensitivity at the request of fishers during consultation on 24 July 2019.
Four sites were surveyed (each approx. 200m long containing 10 pots); three were on chalk bed near the beach launch sites of boats, and one was on a flint and cobble plain.

Site 1: West Sheringham 9 September 2020

> Mostly a flat plain of flint and chalk cobbles, sand and gravel. No areas of chalk bed exposed. This dive was shorter than the others (covering approx. 100m) due to the diving conditions but acts as a useful control site.

Site 2: West Sheringham 11 September 2020

> Algae-topped steep chalk ridges approx. 2m deep with well-defined 5-10m wide gullies of flat chalk bed and sand. Some areas of encrusted cobbles.

Site 3: West Runton 12 September 2020

> Algae-topped sloping chalk ridges approx. 1m deep with poorly-defined 10m wide gullies of mixed ground (sand, chalk bed and cobbles).

Site 4: East Runton 12 September 2020

> Scoured low ridges of chalk approx. 50cms deep with poorly-defined areas of chalk rubble, chalk bed, cobbles and sand. The latter part of the surveyed area had large patches of sand.

2.1 Data collection

The data from each site was collected by a dive team of six people: one dive supervisor (on the surface); two divers using cameras to collect topographical information (imaging team); two divers collecting biological information (bio team); one stand-by diver (on the surface). One diver of each dive pair used wireless communications with bleep-to-voice return to the boat and a delayed surface marker buoy (DSMB) as a reserve in the event of communications failure.

The dive boat was positioned at one end of the randomly chosen shank of pots in the area to be investigated. The imaging team descended first at the start of slack water. Following a communications check, the imaging team initiated recording and followed the shank of pots (one diver either side), approximately 2m apart from each other and approximately 1m above the reef pointing the cameras in a consistent direction and moving at steady speed. After each pot was encountered an A4-sized position marker, used as a control site, was laid by one of the divers approximately halfway between the pot and next pot along the shank (they swam ahead by a random number of fin kicks, placed the marker under the shank and returned to buddy to resume filming). Markers were placed approx. 5-10m away from an encountered pot. Once the shank ended or the maximum dive time was reached the cameras were deactivated, DSMB released and divers returned to surface and boat.

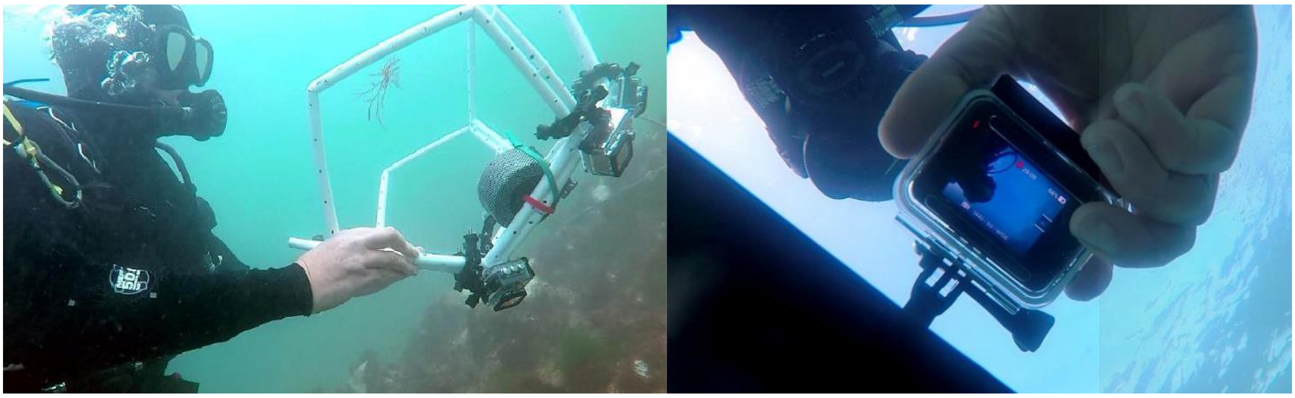
The bio dive team started their dive with a communications check and then performed a standard habitat characterisation survey. They followed the imaging dive team, on both sides of the shank with one diver using a single camera to record any damage observed on the chalk. When they encountered a pot or a control marker one diver laid a 2m reference line after the pot or marker and recorded all commercial crustacean (*H. gammarus* and *C. pagurus*) species openly visible in a $2m^2$

quadrat. They noted the size (adult, juvenile) determined by catch limits of each species (115mm carapace width for *C. pagurus* and 87mm carapace length for *H. gammarus*). Each diver carried two reference guides for judging size. Once the species count was completed the diver tested chalk hardness at the marker or pot, then collected the control marker. Meanwhile the other diver recorded information about the pot: dimensions; material; coatings; number of entries and size; number of escapes and size if any; species in the pot and size; and lastly the presence of bait and its condition. Once at the end of the shank of pots or when maximum dive time was reached they released a DSMB and surfaced to return to the boat.

2.1.1 Imaging

The imaging team divers were each equipped with an array of six cameras on half of the frame called URCHIN produced by University of Essex for rapid monitoring using three dimensional photogrammetry (3DPG). URCHIN consists of a 50cm half dodecahedron plastic frame with five SJCAM action cameras and one GoPro attached, all set to video mode (see Figure 7). This was weighted to be neutrally buoyant.

Figure 7: Collecting video footage using the URCHIN six camera array (left). Activating the cameras manually (right).



2.1.2 Habitat characterisation survey

The bio team performed a habitat characterisation survey that includes physical features of the site (description, depths and orientation of prominent features), physical characteristics (structure of habitat, depth, orientation, rugosity and levels of heterogeneity), community characteristics (community present noting dominant and characterising species) and species abundances in the area focusing on dominant and characterising species first, but also non-native species.

2.1.3 Chalk hardness sampling

This data was collected by using three different materials to scratch the surface of the chalk. These were white plastic stick (cut to thin strip approximately 2 cm wide to a sharp tip), copper nails and steel nails. If the chalk was easily scraped with the plastic it meant the chalk was soft and didn't need any further testing. If it didn't scrape with the plastic the copper was used (indicating medium softness) and if it didn't scrape with the copper, the steel nail was used (indicating hard chalk). One of the bio dive team carried a chalk hardness sampling kit. The chalk was rubbed at writing pressure by the diver to test the hardness. If crumbling or flaking is observed then the progress of tools is stopped (Evans 2019).

2.1.4 Commercial species count

The bio dive team counted (tally) on a dive slate all the commercial species they encountered in the $2m^2$ quadrat immediately after either a pot or control marker. The divers were equipped with a measure for crab and lobster size to measure the carapace where size estimation was borderline. Individuals that were very large i.e. estimated to be too large to fit through the aperture of a standard pot, were also recorded (subsequently this information was merged with the adult category). The recording slate was laid out as Figure 8.

Figure 8: Layout of the recording slate for the bio dive team.

	H. gammarus			**C. pagurus**		
	Juv	*Adult*	*V. large*	*Juv*	*Adult*	*V. large*
Pot 1	IIII		I			I
Control 1	IIII			IIII/ III		
Pot 2	II		II			
Control 2		I			II	

2.2 Data analysis

The videos were pre-processed by extracting frames at one per second and colour corrected. The stills were then processed into 3D models of each pot and control marker using Agisoft Metashape on medium quality image alignment (80k key point limit; 40k tie point limit) and medium quality dense cloud construction (similar default settings to Young and others 2017). The size of the pot or the marker was used to scale the model.

2.2.1 Chalk bed complexity

Structural complexity is often used as a measure of health in marine systems. More complex habitats show increased biodiversity and resilience to environmental change and spot damage (Young 2017). There are many measures of complexity used; however, the most common of these, rugosity, can be assessed in-situ and ex-situ. Other complexity metrics can be exclusive to photogrammetric measurement such as those used in this study (vector dispersion and fractal dimension). Each of these complexity metrics have their own benefits and are suited to different environmental questions.

Rugosity (*R*) is a ratio of the contoured distance to linear distance over a straight line. This metric is universally used as it is easily replicable and comparable to historical data, where it was often the only metric available. This metric is the least accurate of those used in this study.

Vector dispersion (*1/k*) is a measure of the uniformity of the cosine angles found in a triangular mesh overlaid on an area. Though it is only feasible as a photogrammetric complexity assessment due to the near impossibility of *in-situ* measurement, it is often seen as a highly accurate measure of complexity across an entire surface instead of small sections of it (as with rugosity) and is becoming more prevalent with the increased use of photogrammetry survey technology.

The fractal dimension (*D*) of a system shows complexity in relation to varying size scales, allowing organism interaction to be assessed. It assesses the number of times an object of set size needs to be replicated to cover an area and represents how well organisms of different sizes can interact with an environment.

Each pot and marker have associated rugosity, fractal dimension and vector dispersion measurements using a 2m^2 sampling quadrant immediately after the feature (using Rhinoceros 3D, a commercial 3D computer-aided design software application, following a method based on Young and others 2017). The average (mean, median, standard deviation, min and max) of these measures were used for measures of complexity.

2.2.2 Commercial species abundance

Totals for each quadrat area were compared between pot vs marker and between sites, as well as correlated to chalk bed complexity.

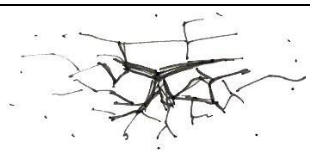
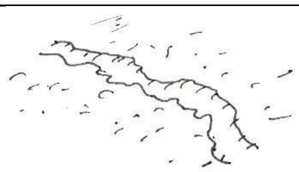
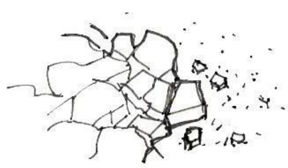
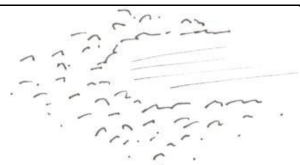
2.2.3 Damage assessment

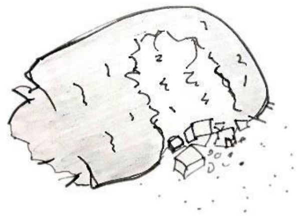
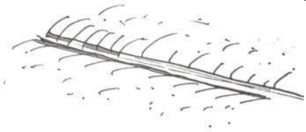
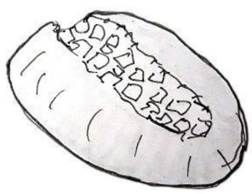
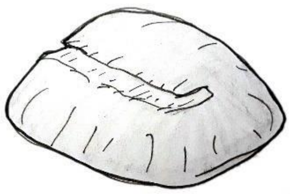
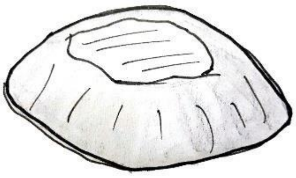
In order to understand the types of impact that were possible on the chalk bed, the team were asked to look out for different types of impact during the surveys and one of the bio divers was given a GoPro to collect *adhoc* video evidence of impacts encountered. Based on the video transect evidence, the *adhoc* video evidence, anecdotal evidence from the dive team and evidence from the project consultants,11 types of distinct impact categories were identified along with the theoretical causes based on expert judgement (see Table 1 and Appendix III for photographic examples).

The downward facing video from each URCHIN was used to categorise all evidence of impact seen in two 2m wide belt transects along either side of the shank. Three annotators evaluated each video independently issuing a category before consolidating. Recent impacts to the chalk are characterised by bright white exposed chalk with angular edges. Severity was categorised as the degree of disturbance to the chalk bed or how much chalk is removed by the impact:

- low (surface layer of chalk removed)
- medium (structure broken but not removed)
- high (structure is broken and removed)

Table 1: Categorisation of the types of impact that could be observed on the chalk bed, including the most likely cause and severity.

Type	Abbrev	Description	Diagram	Most likely human cause	Most likely natural cause	Severity
Strike	STR	Top down vertical strike with a visible impact site and shattered chalk in edged pieces		Pot, Anchor		Med
Drag	DRA	Single lines of chalk indentations of unequal width		Pot, Anchor		Low
Lift	LIF	Shattered chalk in edged pieces with one edge lifted out		Pot, Anchor		High
Abrasion	ABR	Rubbing of epifauna and chalk creating a flattened horizontal plane		Pot, Anchor, Rope	Scour	Low

Grating	GRA	Rubbing of epifauna and chalk on non-horizontal areas creating uneven grooves and chalk debris below the impact site		Pot, Anchor	Scour	High
Angular rubble	RUB	Clean angular chalk cobbles that indicate disturbance but with no clear cause (see above)		Pot, Anchor	Water movement	High
Burn	BUR	Single line of vertical indentation of approximate equal width		Rope		Low
Saw	SAW	Broken angular rubble in a line as a result of continued vertical burns		Rope		High
Cut	CUT	Single line of horizontal indentation of approximate equal width		Rope		Med
Level shear	LSH	Horizontal and flat area of exposed chalk as a result of a complete cut		Rope		High
Unlevel shear	USH	Flat (but not necessarily horizontal or level) area of exposed chalk as a result of an incomplete cut or large amount of chalk disturbance in one impact		Pot, Anchor, Rope	Water movement	High

The protocol for annotation was as follows:

- Each annotator reviewed the footage independently and marked the timecode, damage category and damage cause (the latter in the case of Annotator A only) when the observation was in the centre of the screen. In addition to the abbreviations for damage, the annotator also noted the start of the transect (START), the end of the transect (END), a pot (POT), a position marker (CONTROL), or an anchor (ANCHOR). If the observation was larger than the $2m^2$ frame of the transect an additional observation was recorded.

- The annotations were compiled into a single Excel spreadsheet (xls).
- Working from the last to the first timecodes, the damage timecodes were aligned between annotators. Incidents within <4 secs of another annotator's observation was considered the same incident and placed on the same line in the spreadsheet (even if the category was not the same).
- The categories START, ANCHOR, POT, CONTROL, END were added to the consolidated column (these were the most objective categories and used as markers going through the rest of the data).
- Each incident of damage was reviewed by the consolidator (Annotator A). Incidents supported by two or more annotators were included. Incidents with support from only one annotator were reviewed for inclusion but usually discarded. The final category for the incident was decided by the consolidator.
- Once each transect had a final, consolidated set of damage incidents, both sides of the transect were reviewed to ensure incidents were not double counted, which was likely to be the case for incidents along the rope. Duplicates were removed from the secondary URCHIN transect data.

The two sides of the transect were finally combined for data analysis (approximately 200m x 10m transect).

2.2.4 Statistical analysis

Statistical analyses of the variations between sites, abundances and complexity were performed using chi-square and t-tests (paired and unpaired). Pearson correlation coefficients were used to test correlations between variables. An alpha value of .01 was used for statistical significance.

3 Results

We hypothesised that some areas of the chalk bed provide higher productivity (defined as abundance of commercial crustaceans) due to the high complexity of features. These provided refuge for large, productive individuals and, due to the territorial nature of crustaceans, some juveniles will be forced out of these areas and move along the reef to find refuge in other areas.

Four sites were surveyed by two pairs of divers along a shank of 10 pots. The most pots surveyed in a single dive was five because of dive time limits. Three sites were on rugged chalk bed habitat and one was on flint/chalk cobble plain. Biological and imaging data was collected but only the imaging data and crustacean counts have been analysed for this report. The raw biological data is in the Appendices.

3.1 Comparison of complexity between sites

All four sites were compared with three measures of complexity: rugosity; vector dispersion; and fractal dimension. The aim was to identify high level characteristics of the sites before investigating species abundance and human damage. Figure 9 shows two examples of models of the chalk bed that were produced by processing the images from the cameras on the URCHIN. The 3D model (top, seen in perspective) was scaled based on either the size of the pot in the model or the size of the control marker. A virtual 2m^2 quadrat was created in the model in order to compute the complexity measurements. A 3x3 grid was overlaid from a plan view (Figure 9, second image) that produced six measurements of rugosity per quadrat, with the representative lines also shown below. In a similar way, 64 measurements of vector dispersion and four measurements of fractal dimension (one per scale) were produced per quadrat (not shown in the figure). All models and measurements are available in the data resources outlined in Appendix IV.

Table 2: Summary rugosity measurements.

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	36	0.0488	0.0429	0.0235	0.0178	0.1323
WEST SHERINGHAM (11/9)	60	0.0893	0.0770	0.0531	0.0122	0.2398
WEST RUNTON	60	0.1006	0.0835	0.0859	0.0223	0.4251
EAST RUNTON	60	0.0937	0.0881	0.0436	0.0305	0.2149

There was a significant difference between the sites when considering rugosity (F(3,212)=6.42455, p=.000348, one-way ANOVA, see Table 2), with the West Sheringham (9/9) flint/chalk cobble site being less rugose than the other sites (p<0.0001, n(96), unpaired t-test). This was expected as the site was a flat chalk/ flint cobble plain. The other three sites were on chalk bed and there was no significant difference in rugosity between them (p=.614, p=.580, p=.384, n(120), unpaired t-tests).

Table 3: Summary vector dispersion measurements.

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	384	0.0759	0.0728	0.0382	0.0125	0.2341
WEST SHERINGHAM (11/9)	640	0.0792	0.0706	0.0547	-0.0234	0.3680
WEST RUNTON	640	0.0911	0.0767	0.0639	-0.0106	0.3990
EAST RUNTON	640	0.0921	0.0828	0.0540	-0.0148	0.3043

Unlike rugosity, there is a significant difference between the Sheringham and Runton sites when considering vector dispersion (p<.001, n(1280)/n(1024), unpaired t-tests), see Table 3. There was no significant difference between the two Sheringham sites (chalk/flint cobble plain and chalk sites) (p=.31, n(1024), unpaired t-test). There was also no significant difference between the two Runton sites (p=0.7464, n(1280), unpaired t-test). This may be due to the West Sheringham chalk bed being very angular i.e., the top of the ridges and bottoms of the gullies were flat (similar to the chalk plain site) and the ridges were sheer which was not sufficiently captured in our surveying methodology. The Runton sites had a mix of low sloping ridges and rubble that may contribute to a more complex terrain (when considering vector dispersion).

Table 4: Summary fractal dimension (60-30cm) measurements

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	6	2.0005	2.0007	0.0008	1.9995	2.0017
WEST SHERINGHAM (11/9)	10	2.0265	2.0270	0.0235	2.0053	2.0862
WEST RUNTON	10	2.0339	2.0214	0.0429	2.0063	2.1501
EAST RUNTON	10	2.0053	2.0072	0.0176	1.9597	2.0222

Table 5: Summary fractal dimension (30-15cm) measurements

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	6	2.0039	2.0034	0.0029	2.0010	2.0073
WEST SHERINGHAM (11/9)	10	2.0272	2.0250	0.0144	2.0120	2.0551
WEST RUNTON	10	2.0381	2.0313	0.0296	2.0192	2.1203
EAST RUNTON	10	2.0191	2.0180	0.0093	2.0091	2.0384

Table 6: Summary fractal dimension (15-5cm) measurements

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	6	2.0120	2.0090	0.0074	2.0062	2.0263
WEST SHERINGHAM (11/9)	10	2.0396	2.0356	0.0294	2.0101	2.1151
WEST RUNTON	10	2.0429	2.0351	0.0220	2.0205	2.0946
EAST RUNTON	10	2.0382	2.0371	0.0121	2.0187	2.0562

Table 7: Summary fractal dimension (5-1cm) measurements

	N	MEAN	MEDIAN	SD	MIN	MAX
WEST SHERINGHAM (9/9)	6	2.0338	2.0387	0.0114	2.0175	2.0444
WEST SHERINGHAM (11/9)	10	2.0428	2.0413	0.0136	2.0278	2.0684
WEST RUNTON	10	2.0425	2.0423	0.0161	2.0215	2.0644
EAST RUNTON	10	2.0510	2.0484	0.0138	2.0349	2.0781

All four sites were also compared across four fractal dimension scales. There was no significant difference between the sites when considering the 60-30cm scale (F(3,32)=2.94366, p=0.047772, one-way ANOVA, Table 4), the 15-5cm scale (F(3,32)=3.19211, p=0.03667, one-way ANOVA, Table 6) and the 5-1cm scale (F(3,32)=1.93538, p=0.143707, one-way ANOVA, Table 7). However there was a difference on the 30-15cm scale between the West Sheringham (9/9) site chalk/flint cobble plain site and the other chalk bed sites (p=0.0017 and p=0.0149, n(16), unpaired t-tests) but there was no significant difference between the chalk bed sites (p=0.3133, p=0.1516, p=0.0697, n(20), unpaired t-tests), see Table 5, at this scale. These results are in line with the results of the rugosity analysis, indicating that the chalk/flint cobble plain at the 30-15cm scale is significantly different to the chalk bed.

West Sheringham 11 Sept. Pot 1

High rugosity chalk bed (R = 0.1013)

West Sheringham 09 Sept. Pot 1

Low rugosity chalk and cobble plain (R = 0.0318)

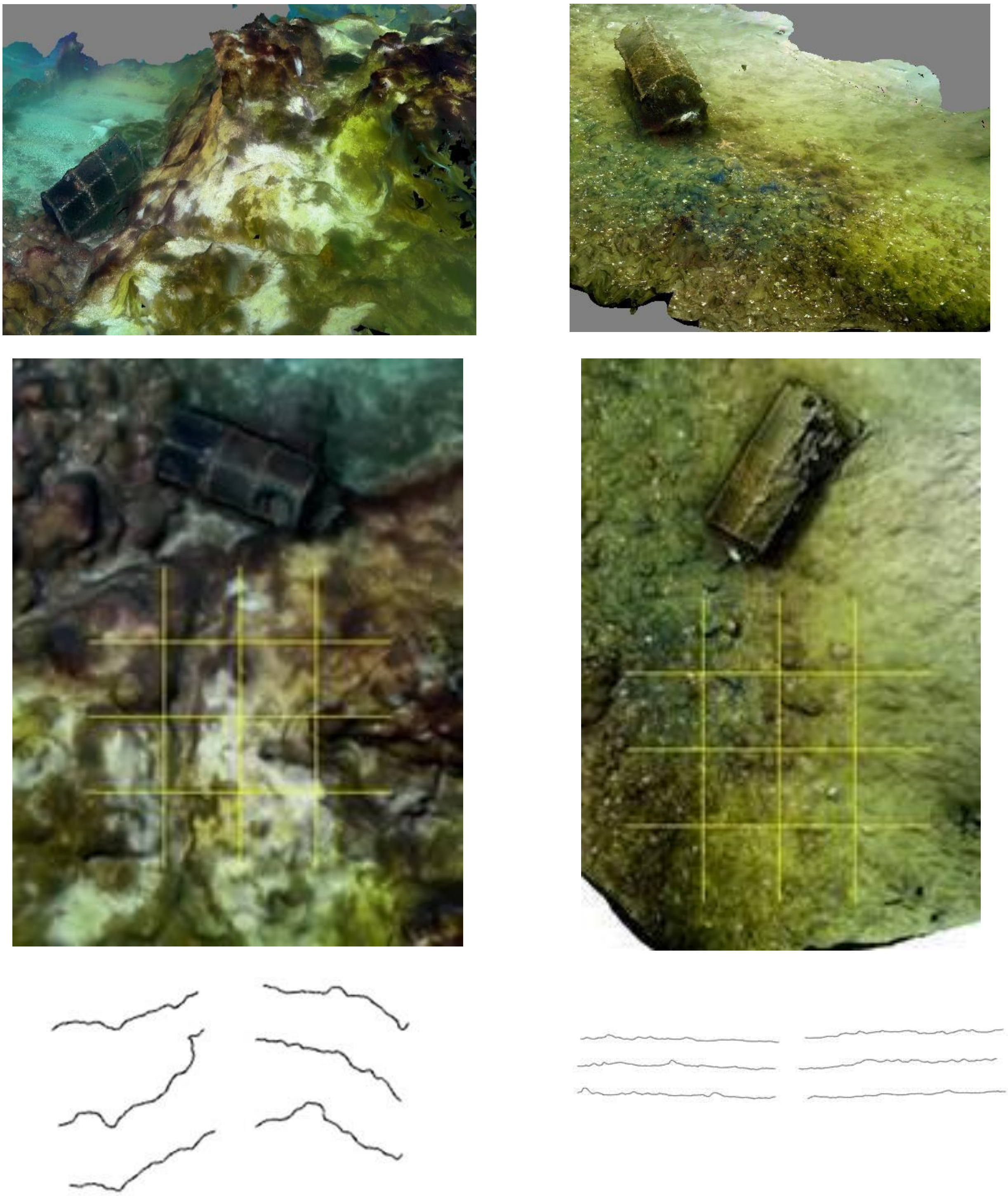


Figure 9: Examples of two quadrats of different rugosity, showing a 3D model, plan view with rugosity markers, and extracted rugosity markers.

3.2 Species abundance at pots and control sites

The survey methodology investigated quadrats that were either adjacent to a pot or approximately halfway between pots (control) along the shank. The abundance counts of the quadrats did not include the animals that were in the pot; however, it is conceivable that the pot could interfere with the abundance of its surrounding area (by capturing and retaining). The abundance of lobsters and crabs in total, as juveniles and as adults, did not vary significantly between pot sites and control sites ($p>0.05$, unpaired t-test, see Table 8). Thus we conclude that the proximity of the pot to the surveyed quadrat does not have a significant effect on the results and therefore pot and control sites were hereafter not differentiated for the purpose of abundance. These results indicate that potting effort (in this shank configuration) does not significantly reduce local abundance of adult or juvenile commercial crustaceans in the immediate area (within approximately 5m); however, the results do not tell us whether fishing effort reduces abundance in a wider area (e.g., by comparing a 200m fished area with an unfished control area) and is beyond the scope of this survey.

Table 8: Crustacean abundance (mean) variation between control and pot quadrats, unpaired t-test (N=24)

	CONTROL	POT	T	*P*
TOTAL SPECIES ABUNDANCE	1.50 SD(1.24)	2.33 SD(3.85)	0.714	0.483
CRABS				
TOTAL ABUNDANCE	1.50 SD(1.24)	2.08 SD(3.92)	0.492	0.628
ADULT ABUNDANCE	0.17 SD(0.39)	0.33 SD(0.65)	0.761	0.455
JUVENILE ABUNDANCE	1.33 SD(1.37)	1.75 SD(3.96)	0.344	0.734
LOBSTERS				
TOTAL ABUNDANCE	0 SD(0)	0.25 SD(0.62)	1.393	0.178
ADULT ABUNDANCE	0 SD(0)	0.08 SD(0.29)	1.000	0.328
JUVENILE ABUNDANCE	0 SD(0)	0.17 SD(0.58)	1.000	0.328

3.3 Complexity between pot and control sites

We assumed that the position of a pot along a shank would not target areas of higher complexity due to the nature of how the pots are set and the variability of where the pot could land from release on a 2m tether; however, in areas of high rugosity, it is possible the pot could move and settle at the bottom or edges of large features. The results in Table 9 show there was a difference in rugosity and vector dispersion between control and pot quadrats. From these results we conclude that either pots are settling in areas of higher complexity or that the positioning of the control markers was biased towards less complex areas (meaning that the overall assessment of complexity at a site is likely to be lower than stated).

Table 9: Variation between pot and control quadrats complexity, unpaired t-tests

	N	CONTROL	POT	T	*P*
RUGOSITY, *R*	216	0.0768 SD(0.0383)	0.0970 SD(0.0761)	2.2458	0.0147
VECTOR DISPERSION, *1/K*	2304	0.0801 SD(0.0477)	0.0910 SD(0.0616)	4.7274	<0.0001

FRACTAL DIMENSION,					
$D_{30\text{-}60}$	36	2.0163 SD(0.0253)	2.0204 SD(0.0342)	0.4018	0.6903
$D_{15\text{-}30}$	36	2.0238 SD(0.0140)	2.02442 SD(0.0265)	0.0918	0.9274
$D_{5\text{-}15}$	36	2.0370 SD(0.0235)	2.03408 SD(0.0222)	0.3807	0.7058
$D_{1\text{-}5}$	36	2.0448 SD(0.0112)	2.04221 SD(0.0177)	0.5169	0.6086

3.4 Species abundance variation with complexity

In order to investigate the first two research questions of this study, the species abundance of the quadrats were correlated to the complexity measures: median rugosity (*R*), median vector dispersion (*1/k*) and fractal dimension (*D*) on four scales.

> *RQ1 Areas containing large, complex chalk features will have a higher abundance of adult commercial crustaceans than the flatter areas of chalk bedrock.*
>
> *RQ2 Juvenile commercial crustacean density will be similar across all chalk areas.*

Only three lobsters were observed in the 24 quadrats and thus were not included in the analysis.

Table 10 indicates that adult crab abundance is moderately correlated to rugosity ($r(22)=0.6717$, $p<0.001$, Pearson correlation) but juvenile crab abundance is not. Vector dispersion does not correlate to crab abundance, see Table 11. Fractal dimension moderately correlates to adult crab abundance at the 60-30cm and 30-15cm scales (see Tables 12-13) but juvenile crab abundance does not. Fractal dimension at 15-5cm and 5-1cm scales do not correlate with crab abundance (see Tables 14-15).

Table 10: Pearson correlation coefficients between median rugosity and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	-0.0214	0.0005	0.9224
JUVENILE ABUNDANCE	-0.1440	0.0207	0.5020
ADULT ABUNDANCE	0.6717	0.4512	**0.0003**

Table 11: Pearson correlation coefficients between median vector dispersion and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	-0.1597	0.0255	0.4580
JUVENILE ABUNDANCE	-0.2142	0.0459	0.3153
ADULT ABUNDANCE	0.3113	0.0969	0.1387

Table 12: Pearson correlation coefficients between fractal dimension (60-30cm) and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	-0.1061	0.0113	0.6220
JUVENILE ABUNDANCE	0.0063	0	0.9767
ADULT ABUNDANCE	0.5361	0.2874	**0.0069**

Table 13: Pearson correlation coefficients between fractal dimension (30-15cm) and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	0.0555	0.0031	0.7967
JUVENILE ABUNDANCE	-0.0483	0.0023	0.8237
ADULT ABUNDANCE	0.5627	0.3166	**0.0042**

Table 14: Pearson correlation coefficients between fractal dimension (15-5cm) and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	0.0457	0.0021	0.8321
JUVENILE ABUNDANCE	0.0158	0.0002	0.9416
ADULT ABUNDANCE	0.1592	0.0253	0.4576

Table 15: Pearson correlation coefficients between fractal dimension (5-1cm) and crab abundance (N=24)

CRABS	R	R^2	P
TOTAL ABUNDANCE	-0.088	0.0077	0.6826
JUVENILE ABUNDANCE	-0.1117	0.0125	0.6056
ADULT ABUNDANCE	0.1372	0.0188	0.5226

These findings support our research hypotheses that adult crabs would be in areas of higher complexity and juvenile crabs would be in all areas (i.e., not correlated to areas of high complexity). Caution should be observed with the findings as only six adult crabs were observed in the 24 quadrats and a larger scale study would reinforce these findings and further investigate whether a complexity correlation for adults would also be observed for lobsters.

3.5 Categorising human impact on chalk beds

We hypothesised that chalk bed areas of high rugosity and complexity are more vulnerable to human impacts due to the soft composition of the substrate, thus:

> *RQ3 Areas with large, complex chalk features will show evidence of more impact than the flatter areas of chalk bedrock.*

A proposed set of damage categorisations were presented to the dive and annotation team prior to data collection and annotation review. The initial suggestions were refined over the course of observations to ensure that the categorisation was comprehensive and covered all the impact that was observed. These final categories are detailed in the methodology (see Section 2.3). The final categories were endorsed by the report consultants. This categorisation scheme is, in itself, a unique output of this investigation.

3.6 Damage variation across sites

The video evidence of each site was reviewed by three independent annotators according to the annotation protocol outlined in the methodology:

> Annotator A: Marine technology academic from the University of Essex with considerable experience of the sites. Devised the categorisation scheme and dived all sites during the survey. Trained the other annotators and performed the consolidation steps.

Annotator B: Marine technology PhD student from the University of Essex experienced at annotating footage for analysis.

Annotator C: Environment management intern at Natural England.

The damage that was observed across the four dive sites is detailed in Table 16 (where all incidents are observed) and Table 17 (damage attributed to human activity). The site dived on 9 September 2019 at West Sheringham was a flint/chalk cobble plain and there were no confirmed observations of damage recorded so this site is excluded from the results. The remaining three sites were primarily chalk bed, with some sand gullies, cobble areas and algae in places. There were 65 incidents of human attributed damage of different severity across the three subtidal chalk sites investigated. Impacts which were categorised as human attributed are those that could only be from a human cause and those where the cause was present, for example incidents where a pot was observed to be causing an impact.

Table 16: Damage per type at each site (all incidents)

	STR	DRA	LIF	ABR	GRA	RUB	SAW	BUR	CUT	LSH	USH	TOTAL
W SHER. (11/9)	2	1	0	49	3	5	1	2	1	7	11	82
W RUNTON	3	0	0	20	3	3	0	1	0	1	6	37
E RUNTON	12	0	2	12	4	26	1	0	1	1	13	72

Table 17: Damage per type at each site (attributed to human activity)

	STR	DRA	LIF	ABR	GRA	RUB	SAW	BUR	CUT	LSH	USH	TOTAL
W SHER (11/9)	2	1	0	14	1	1	1	2	1	7	0	30
W RUNTON	3	0	0	7	0	0	0	1	0	1	0	12
E RUNTON	12	0	2	6	0	0	1	0	1	1	0	23

It was not possible to statistically analyse all the damage categories due to the low incidence in some cells; however, this information is presented as radar charts (Figures 10 and 11) to visualise characteristics of each site and the types of damage that were observed.

Figure 10: Radar charts showing all incidents of damage at each site (scale 0-50).

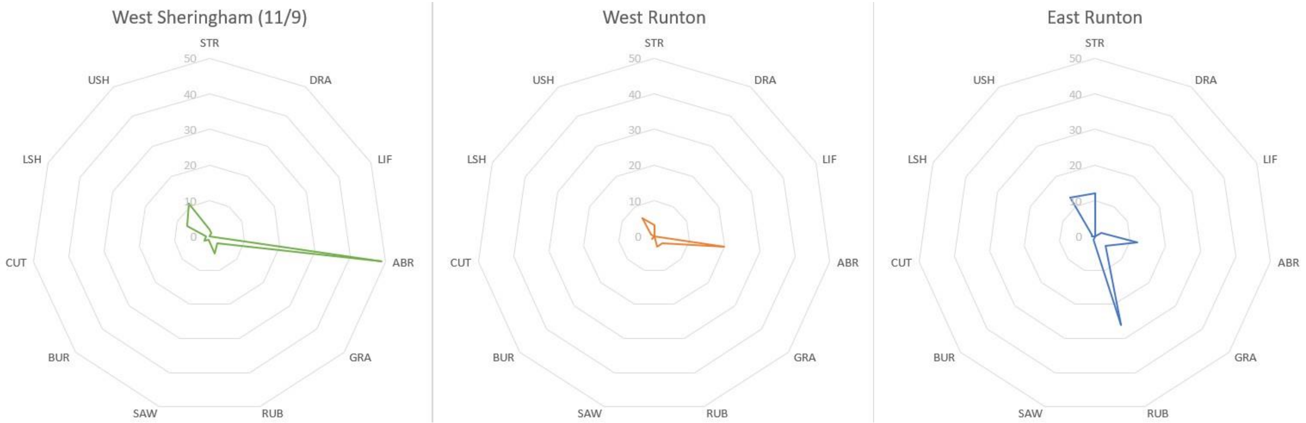
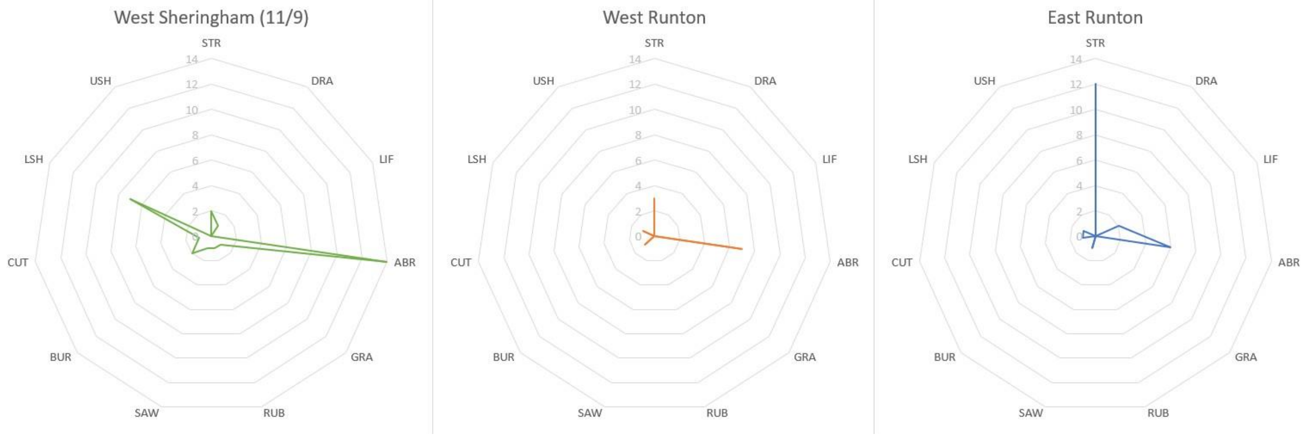


Figure 11: Radar charts showing damage attributed to human activity at each site (scale 0-14).

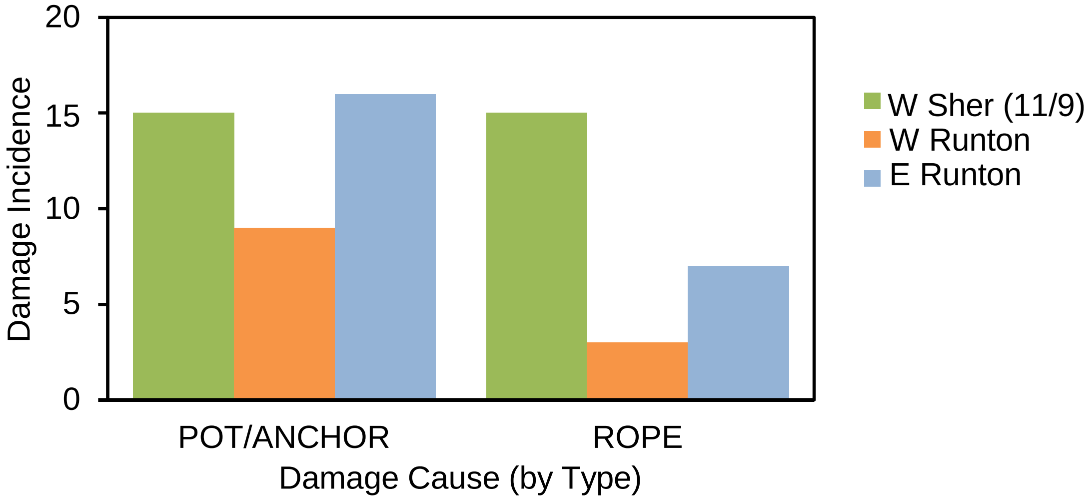


The radar charts of all incidents of damage (Figure 10) highlight a number of characteristics of the chalk bed at each site. West Sheringham chalk displays a very high amount of abrasion with some shears and strike damage observed. West Runton, a similar site but with flatter features, shows the same damage characteristics but in fewer number. East Runton on the other hand is quite distinct, with a high occurrence of rubble, strikes and unlevel shears, and comparatively less abrasions. This is consistent with our understanding of the chemical composition of the chalk bed at this location: it is much softer and pitted than the other sites and seems more prone to damage from a direct force (creating considerable patches of rubble).

The radar charts of incidents of damage attributed to human activity (Figure 11) do not show the high occurrence of rubble at East Runton because it is not a damage type that can be attributed to human activity unless there is a cause present. What is noticeable is the higher occurrence of strike damage at East Runton in comparison to the other sites, again indicating the chalk bed at this location has a different composition that is more susceptible to shattering. There is a high occurrence of level shears at the West Sheringham chalk site, consistent with observations that the raised chalk features are rubbed flat at the top by ropes pulled taught by pots settling in gullies.

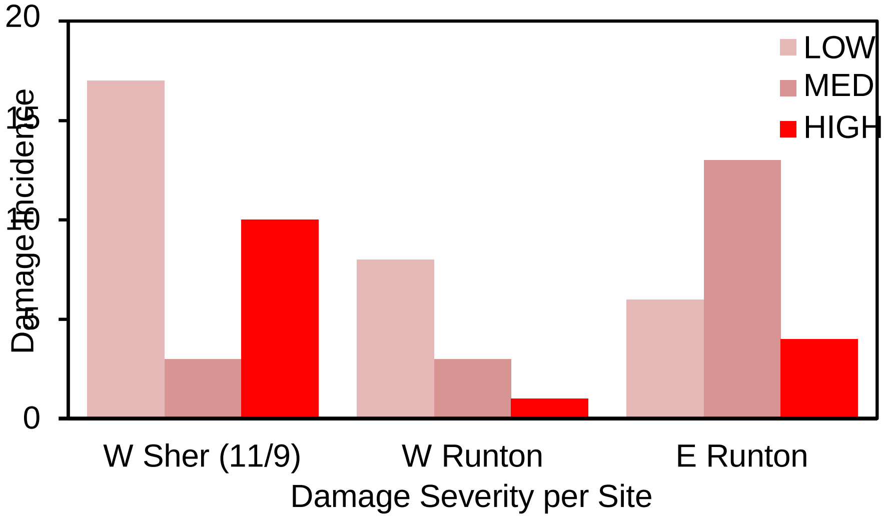
When considering damage attributed to human activity, there are two types we know interact with the chalk bed in different ways: pots/anchors that strike the substrate when they land and move slightly due to water movement over time; and ropes that are used to retrieve the pots (vertical motion), move with the fisher’s boat (horizontal motion in the direction of the rope) and move with water movement (horizontal motion perpendicular to the direction of the rope). We do not observe a statistically significant difference between sites when considering the two types of damage (chi-square (df=4, N=65) = 3.2323, p = .198658), see Figure 12.

Figure 12: Chart showing the occurrence of damage at each site attributed to either pots/anchors or ropes.



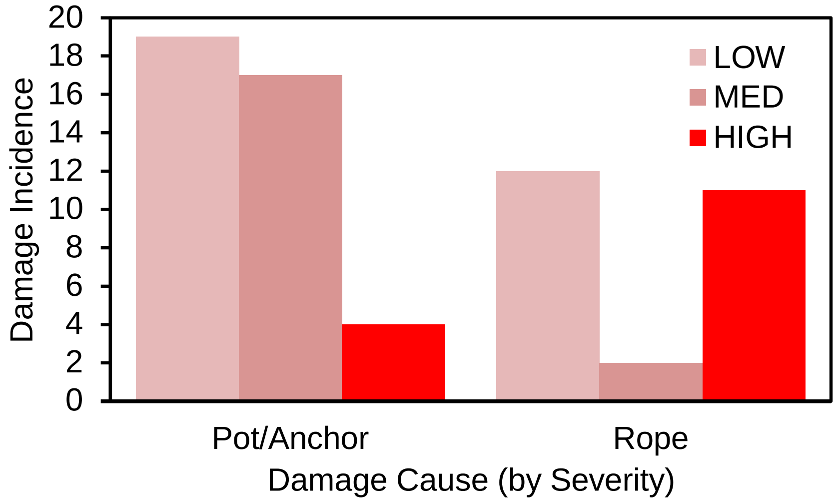
The different categories of damage have the capacity to damage the chalk substrate in different ways, with some only dislodging a small amount of chalk (e.g., abrasion), whilst others can cause a large amount of chalk to be removed from the bed (e.g., level shear). We observed a significant difference between the sites in terms of the occurrence of human-attributed impacts categorised by severity (chi-square (df=4, N=65) = 16.2131, p = .002746). We observed that the site with most raised features (West Sheringham) has the highest occurrence of highly severe impacts, as well as low severity impact (due to the amount of abrasions observed). East Runton shows considerable medium severity impacts, due to the amount of strikes observed, see Figure 13.

Figure 13: Chart showing occurrence of damage categorised by severity.



One of the important aspects of understanding human impact on the chalk bed is whether some activities have more impact than others. Figure 14 shows the incidence of damage caused by two different types of human impact (pots/anchors and rope), classified by the severity of the category of impact. We observe that pots/anchors cause more low and medium severity damage to the chalk bed and ropes cause the most severe damage (chi-square (df=2, N=65) = 13.9719, p = .000925). It is beyond the scope of this study to estimate the equivalence of severity between low, medium and high categories in terms of chalk displaced and complexity lost i.e., for example, we cannot say whether several incidents of abrasion are better or worse than a single incident of level shearing.

Figure 14: Chart showing occurrence of damage caused by different human causes classified by severity.



3.7 Damage variation with complexity

In order to investigate whether human-attributed damage was associated with chalk bed complexity in a more detailed way, each model that was built on the three chalk bed sites (30 in total) were correlated to a sliding window of observed damage along the transect. The window started from the previous pot or control position to the position of the quadrat and ended at the pot or control position after, estimated to be 20m long on the transect. For example, Pot 3's window was from Control 2 to Control 3. Also, Control 5's window was from Pot 5 to Pot 6 (the latter not being modelled, but just used as the marking position). The start of Pot 1's window was from the start of the transect. The results (Tables 18-23) show there is no correlation between damage observed in a 20m section of the transect and any complexity measure, as measured by a representitive 2m^2 quadrat in the centre of the transect section.

Table 18: Pearson correlation coefficients between rugosity and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	0.1544	0.0238	0.4153
ROPE DAMAGE	0.2198	0.0483	0.2432
POT/ANCHOR DAMAGE	-0.0101	0.0001	0.9582

Table 19: Pearson correlation coefficients between vector dispersion and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	-0.0023	0	0.9916
ROPE DAMAGE	-0.1220	0.0149	0.5207
POT/ANCHOR DAMAGE	0.1311	0.0172	0.4899

Table 20: Pearson correlation coefficients between fractal dimension (60-30cm) and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	0.0455	0.0021	0.8113
ROPE DAMAGE	0.0487	0.0024	0.7983
POT/ANCHOR DAMAGE	0.0147	0.0002	0.9385

Table 21: Pearson correlation coefficients between fractal dimension (30-15cm) and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	0.0235	0.0006	0.9019
ROPE DAMAGE	0.0560	0.0031	0.7688
POT/ANCHOR DAMAGE	-0.0263	0.0007	0.8915

Table 22: Pearson correlation coefficients between fractal dimension (15-5cm) and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	0.0784	0.0061	0.6805
ROPE DAMAGE	-0.0111	0.0001	0.9540
POT/ANCHOR DAMAGE	0.1302	0.0170	0.4929

Table 23: Pearson correlation coefficients between fractal dimension (5-1cm) and human-attributed damage (N=30).

	R	R^2	P
TOTAL DAMAGE	0.0524	0.0027	0.7833
ROPE DAMAGE	-0.0831	0.0069	0.6628
POT/ANCHOR DAMAGE	0.1705	0.0291	0.3677

3.8 Biological and geological results

Analysis was undertaken for only some of the biological data gathered during the dive survey. The habitat and species data was a secondary consideration and of varying quality therefore comparisons between sites wasn't possible. All the raw biological data is in Appendix IV and V for completeness.

The hardness testing of chalk undertaken by the divers showed all was easily scraped by the plastic stick indicating the chalk at all sites surveyed was soft and friable. This indicated that the suggested method was too crude for the areas we were looking at and a more refined method is required to differentiate chalk hardness/softness.

3.9 Results summary

- Four sites were tested: one a flat chalk/cobble plain and three on rugged chalk bed.
- The three sites on chalk bed have higher rugosity and greater fractal dimension (30-15cm scale) than the chalk/flint cobble plain. The West Sheringham chalk bed site was similar to the chalk/flint cobble plain on vector dispersion measures possibly due to the angular structure of the ridges.
- There was no statistical difference in abundance of crabs or lobsters between pot and control sites, indicating that **potting effort was not reducing local abundance**.

- There was an indication from rugosity and vector dispersion between pots and control points that pots were either settling in areas of higher complexity or the control points that were chosen were biased towards less complex areas.

- Only three lobsters were observed in 24 quadrats so their abundance was not analysed.

- Adult crab abundance correlates with rugosity and fractal dimension (60-30cm and 30-15cm scales). Juvenile crabs had a high abundance but did not correlate to complexity. This finding supports our first two research questions, that **more adult crabs would be found in areas of higher complexity and juveniles would be distributed across all sites.**

- The three **chalk bed sites showed numerous occurences of low, medium and severe damage** in comparison to the chalk/ flint cobble plain site where no damage was observed.

- West Sheringham and West Runton sites showed similar damage characteristics: abrasion with some shears and strike damage. East Runton on the other hand had a high occurrence of rubble, strikes and unlevel shears, and comparatively less abrasions.

- Human-attributed damage from pots, anchors and ropes interact in a similar way across sites.

- The **severity of damage is different across the sites**, with West Sheringham chalk site most impacted by severe types of human-attributed damage.

- More complex chalk site areas were not statistically correlated with more incidents of human-attributed damage. This does not support the third research question: that more complex areas are at higher risk of damage (and therefore would have a higher occurrence of damage) than less complex areas.

4 Discussion

4.1 Complexity and species abundance

There was a positive correlation between complexity measures and the number of adult crabs *Cancer pagurus*, supporting the hypothesis that areas containing large chalk features would have a higher abundance of large, mature commercial species. As expected, no relationship was seen between complexity measures and juvenile species. The territorial and often cannibalistic nature of adult crabs can lead to them pushing juveniles out of the preferred, more rugged areas of chalk (Neal and Wilson 2008).Consequently, juvenile crustaceans often find suitable refuge in the less complex areas of chalk as, unlike the larger adults, their size enables them to fit into the smaller cracks and fissures.

Lobsters are more catchable on the fringe of rocky reef habitats, but may spend most of their time in the shelter of rocky reefs according to Galparsoro and others (2009) and Geraldi and others (2009). They found that although both patchy areas of rock/sediment and more homogeneous rocky reef habitats may be classified as the same biotope (e.g. CR.MCR.EcCR.FaAlCr), they may host very different densities of lobster and crabs, and levels of species diversity. However, habitat complexity and high species diversity are believed to strongly influence successful settlement and recruitment according to Eggleston and others (1999) and therefore overall abundances of crab and lobster (Hartnoll 1998; Hovel and Lipcius 2001).

The preference of *C. pagurus* for more complex reef habitats has also been observed in previous studies (Hunter and Sayer 2009). This relationship between commercial crustaceans and habitat complexity suggests that a reduction in rugosity of the chalk would also lead to a reduction in abundance of crab and lobsters. This would have knock on affects both on local marine biodiversity and the North Norfolk fishery.

4.2 Human-attributed impact to the chalk bed

Results from the survey show that permanent damage is occurring to the chalk bed as a result of human activity and crab and lobster potting. Previous reports have highlighted that the soft nature of chalk leaves it vulnerable to abrasion pressures generated by static fishing techniques (Hartnoll, 1998; Stephenson and others 2018); however, this is the first time we believe that damage to the physical structure of subtidal chalk from potting activity has been documented and quantified in a scientific study.

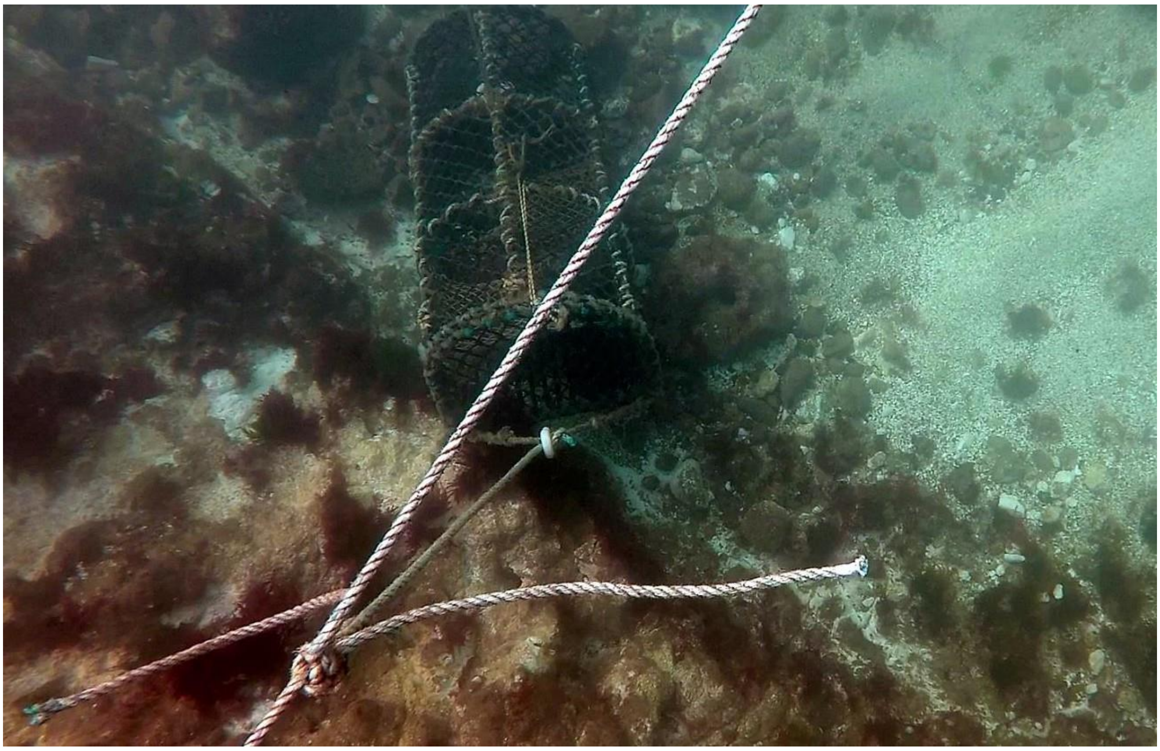
Although each individual incidence of damage observed was small-scale, the additive effect of these small-scale impacts over time could be altering the structure on a larger scale (and therefore biological function of the chalk) in a more rapid and focused way than natural change would be. It was estimated that on a single day in October 2019 up to 8,000 individual pots were deployed on the chalk reef according to observations by Love and others (2019). This was acknowledged to be a very crude estimate of potting activity; however, it does give an indication of the potential for cumulative impacts across the site. This may be further enhanced with the increase in Offshore Renewables activity on the East coast providing compensation payments to fishers for loss of fishing grounds which may then be re-invested in more pots.

Anthropogenic damage tended to be more focused on certain points of the feature, rather than evenly across the feature (for example the shearing of a small elevated piece of chalk, or a visible impact site, with slight indentation lines and chalk rubble) on the chalk sites. The potential for cumulative damage from static fishing activity on subtidal chalk has previously been discussed by Hartnoll (1998), who recognised that the movement of pots, and associated ground lines and anchors, could cause multiple incidents of damage on the seabed.

Damage classification work undertaken on the transect videos showed that rope causes the most severe types of damage, defined as how much chalk is disturbed by an occurrence of that impact. The sites have different characteristics of damage with West Sheringham (chalk site only) and West Runton showing similar damage characteristics: abrasion with some shears and strike damage. East Runton on the other hand had a high occurrence of rubble, strikes and unlevel shears, and comparatively less abrasions, likely due to its different chalk composition. West Sheringham chalk site was found to have the most severe impacts and raised features. Photographic footage of damage to the chalk reef from other sources suggests that the most severe incidents of damage are inflicted by ropes rather than the pots themselves (Spray, 2019).

There is a high occurrence of level shears at West Sheringham chalk site, in line with our expectations that the raised chalk features are rubbed flat at the top by ropes pulled taught by pots settling in gullies. Observations from the dive team note that on several occasions the tether from shank to pot (usually approximately 2m) was not long enough for the pot to reach the sea bed when the shank was laid at West Sheringham. The result is that the pot hangs freely in the gully (Figure 15), causing grating on the chalk ridge walls and pulling the shank rope taught across the top of the chalk ridges, creating the most severe rope damage (e.g., sawing, cutting, burns, level shears, etc). By lengthening the tether when fishing in areas where there are deep gullies, fishers could easily reduce the impact the pot is having on the environment, as well as ensuring the pot is properly set for catch. However too much rope is a hazard to navigation therefore a balanced approach is needed.

Figure 15: A pot hanging in a gully too deep for the tether to allow it to set.



The findings from the survey have identified that some of the chalk damage within the CSCB MCZ can be attributed to the active crab and lobster potting fishing; however, it is acknowledged that some damage can also occur from submerged pots which are not actively used (i.e. lost, stored, or territory marking pots). Although not observed during this survey, it is widely acknowledged that there is a practice of pot storage at sea. A lack of quayside storage facilities in the area means that the practice of storing pots underwater is common, although it is thought that the majority of fishermen relocate their pots onto the flatter ground, beyond the reef, for storage (EIFCA pers. comm. 2019). There are however occasions when stored or lost pots have been observed causing damage to areas of complex outcropping chalk (Spray 2019). Restricting the practice of storing pots underwater, and the provision of adequate quayside storage could, therefore, reduce the damage caused by the crab and lobster fishery on the chalk beds. Furthermore, to protect the chalk beds from damage from lost pots a mechanism should be put in place to report and recover these gears.

In terms of feature protection, any degree of damage attributed from human activity is additive to the natural process of erosion and therefore even small incidents of anthropogenic damage to the chalk could be speeding up natural processes. For example, chalk covered in epifauna is likely to weather at a slower rate than exposed chalk, and therefore small-scale impacts from potting may be speeding up the natural process of erosion, which will eventually impact the structure of the chalk.

4.2.1 Novel Categorisation method

In this report a novel categorisation method was presented (see Table 1) to accurately and consistently describe damage found on the chalk beds at Cromer Shoal Chalk Beds MCZ. This novel method was developed prior to and throughout fieldwork. This method provides insight and valuable information about the state of damage observed along the chalk beds. Enabling continued development throughout the survey allowed capture of all damage types observed. It is hoped and intended that this method continue to be used in future chalk damage evaluation surveys, acting as a standard protocol.

4.3 Damage variation with complexity

All subtidal chalk sites showed numerous incidents of damage, however contrary to the research question RQ3, there was no significant correlation between human-attributed damage incidents and complexity measures. We believe this to be a limitation of the study design as review of the video footage taken of each transect showed that cases of damage were more common on areas of complex outcropping chalk (West Sheringham dived on 11 September 2019), whereas damage noted on areas of flatter chalk was limited to that categorised as abrasion. Future surveys of the site could expand the survey sample to provide more conclusive analyses. No studies were found that explored the relationship between damage and habitat complexity in static fisheries; however, previous work has concluded that the more structurally complex a habitat is, the more adversely affected it may be by fisheries involving bottom-towed gear (Kaiser and others 2003). It is expected that this relationship would also be followed when considering static gears, albeit incidents of damage are likely to be less severe than those seen from fishing with mobile gear.

4.3.1 3D Photogrammetry method

The use of this emerging technology for habitat modelling of temperate reef is novel, as is the use of the technology to evaluate damage to submerged features. By utilising the best available technology for these surveys, in conjunction with traditional dive surveys, we have been able to evaluate and corroborate findings, which validates the use of this technology for future surveys of this type. This minimises the risk of human variation and error in the data collection and analysis, as well as HSE risks associated with dive surveys and the considerable logistical challenges in areas with few facilities for commercial dive surveys.

4.4 Geological features of the chalk bed

During the dive survey data was collected on biological communities and hardness of chalk. This data was not analysed for the purposes of this study but has been collated and will be entered into the JNCC Marine Recorder benthic survey data management system (biological data only).

The hardness testing of chalk that was undertaken by the divers showed that all chalk was easily scraped by the plastic stick indicating all the chalk surveyed was soft and friable and potentially more easily impacted by marine activities.

According to Evans (2019) using measurements in relation to hardness of chalk in combination with other observations and evidence will support general inferences about relative hardness, rather than use of a ‘hardness’ measurement alone. The plastic sheet (cut to point) will substitute for a very hard fingernail and will scratch marls, soft chalks and weathered chalk. Copper nails will scratch all but the hardest chalks, while the soft steel nails should scratch the hardest chalks but won’t leave indentation on flint.

Evans acknowledges that there is inevitable subjectivity in this as other factors will influence from the hardness of the testing materials. These will result from the differing pressures and angles with which the tools are applied. The only way of avoiding this is to take samples for lab testing or to test in situ using a fixed and calibrated device. In the context of a complex dive survey with multiple data collection goals we hoped a relatively crude approach would provide useful information, whereas attempting to refine the method would simply result in diminishing returns for the effort put into the work according to Evans (2019) as well as cause further damage to the protected chalk bed feature. These conclusions are supported by a paper by Mol (2014).

4.5 Limitations of this survey

Although this investigation achieved its goals there were limitations. Due to the surveying method of using quadrats and not transects, observations of lobsters were too low to be usable (three occurrences) and low observations of adult crabs (six in 24 quadrats) make the conclusions less robust (even though the results were statistically significant). Clearly a larger scale study with more data points would provide a more reliable evaluation.

The measurements for complexity were based on a method for assessing tropical coral reefs where the habitat extends laterally across the horizontal plane. In the case of the Cromer Shoal MCZ, the chalk ridges extend perpendicular from the shore, thus measurements using quadrats could easily miss large features, and even if a large feature is captured in a quadrat, some of the measurement lines may be parallel to the feature height change i.e., show low rugosity despite it being a large feature. The survey mostly focused on areas with rugged chalk as they were the areas considered to be most sensitive to impact but wider investigation to include the flatter chalk plain for comparison would be beneficial. The advantage of the video technique using the six-camera URCHIN is that video footage can be reprocessed to build models for different types of analyses. Processing models larger than $2m^2$ become computationally expensive and the conditions observed on temperate reefs make the reconstruction of large-scale 3D models relatively difficult.

This study is the first, we believe, to present a categorisation of impacts on chalk reef. These categorisations were based on expert judgement and consultation with divers. The most likely causes of impact were also based on expert judgement and consultation with partners and are therefore subjective. The creation of this categorisation was extensive; however, the severity attribute is likely to be different per incident observed, for example, a small amount of sawing (a high severity damage type) may be less destructive to the chalk bed than a large amount of abrasion (a low severity damage type). Lab based studies to quantify the extent of damage possible, along with more detailed measurement would provide more insight to this question, but it may prove immaterial when considering recommendations to protect the chalk features.

This study used a six-person dive team for five days, which proved to be very expensive and logistically complex to arrange. As well as training the rotating team for consistent results, the field work suffered from poor weather, boat failure and inconvenient launching facilities. As such, future work may consider using a Remotely Operated Vehicle (ROV) and citizen science for data collection.

5 Recommendations

It is proposed that the methods developed during this survey can be used as a basis to conduct further survey work, which will aim to gather more photographic data along pot shanks, to increase the existing survey sample. The novel categorisation method for damage of chalk features, and the use of 3D photogrammetry, is intended to be published by the University of Essex as part of PhD research. By utilising a ROV operated from a fishing vessel, we hope that this technology will allow for a wider area of survey and help overcome some of the financial and logistical challenges faced when using a dive team. Adding to the existing transect data will allow relationships between complexity, damage and species populations to be further explored, and increase the statistical robustness of any relationships identified.

Much of the severe damage observed during the survey was caused by rope, rather than by the pots themselves. Although pots are a necessary component of the fishery, technologies are already emerging that can negate the need for the ropes that connect them. If this technology is viable in the North Norfolk fishery then, based on the data obtained from this survey, just under 50% of the recorded damage could be avoided. Remotely triggered potting technology is already being trialled in Maine, USA and in Scotland to reduce the risk of entanglement to marine mammals (Sawicki 2019; Baumgartner and others 2020). This technology could be trialled on the chalk beds to ascertain whether remotely triggered methods would result in less damage to areas of elevated chalk and, if so, whether this method would be logistically and economically viable for the fishery. Further survey work will need to incorporate a control site with no fishing activity so comparisons can be made with the traditionally fished activity and new gear types.

Complete removal of pot storage practices and marking of territories is also recommended as this eliminates the risk of damage and also negates the risk of ghost fishing gear within the designated site causing harm to habitats and target and non-target species. Provision of alternatives may be a consideration to ensure this practice is halted.

Greater understanding of current fishing levels and practices are also required to ensure the level of potential impact can be properly understood. Counts of pots deployed from vessels and from shore as well as observations of pot deployment and recovery would help improve this understanding and make more accurate assessments of impacts. A thorough MCZ assessment of current levels of activity is essential to ensure risks to the conservation objectives of the site are minimised. An adaptive risk management (ARM) approach is recommended to ensure the best available evidence is used to inform appropriate and proportionate management decisions.

All these recommendations need to be conducted in partnership with regulators, conservation bodies, academia, non-government organisations (NGOs) and stakeholders to ensure there is engagement and transparency throughout the process. It is proposed that re-invigoration of the North Norfolk Fisheries Forum be used to actively engage the fishing industry.

6 Conclusion

Two out of three of our research questions were answered positively. These were:

- *RQ1 Areas containing large, complex chalk features will have a higher abundance of adult commercial crustaceans than the flatter areas of chalk bedrock.*

- *RQ2 Juvenile commercial crustacean density will be similar across all chalk areas.*

Evidence for adult crabs showing a preference for more complex habitats was demonstrated but not for adult lobsters as so few were seen on the survey outside the pots. Juvenile crabs were ubiquitous on all the dives in all the sites including the chalk/flint cobble habitat supporting the theory that competition over territory favours the larger adults inhabiting the more complex and protective habitats.

Evidence that potting effort is not reducing local abundance of crabs and lobsters from the survey was demonstrated in the immediate locality of the pots but for certainty, there would need to be a control site of sufficient size with no fishing activity for comparison over a longer timescale and wider area for future study. Additionally, we hypothesised that chalk bed areas of high rugosity and complexity are more vulnerable to human impacts due to the soft composition of the substrate, thus:

- *RQ3 Areas with large, complex chalk features will show evidence of more impact than the flatter areas of chalk bedrock.*

The three chalk bed sites showed numerous occurences of low, medium and severe damage in comparison to the chalk/ flint cobble plain site where no damage was observed; however, there was no significant correlation between human-attributed damage incidents and complexity measures. In order to make inferences about the levels of this in comparison to naturally occurring damage, further surveys with a control site would need to be undertaken.

Severity of damage is different across the sites, with West Sheringham most impacted by severe types of human-attributed damage. West Sheringham and West Runton sites showed similar damage characteristics: abrasion with some shears and strike damage. East Runton on the other hand had a high occurrence of rubble, strikes and unlevel shears, and comparatively less abrasions. It is evident that pots, anchors and ropes cause low to high severity types of damage to the chalk bed.

As this study is possibly the first (as far as we are aware through extensive literature review and consultation with colleagues) to look at impacts on structure of chalk habitat from potting activity there were few previous studies from which to compare. The methods are unique and therefore the limitations and unconscious biases have been highlighted. Further surveys are recommended in order to fill data gaps and make findings more statiscally robust.

The findings of this investigation will be shared with Eastern IFCA, fishers, local councillors and conservation groups in forums to capture feedback on the collected evidence and determine positive action and next steps. Indicative 3D models of sections of the reef will be made freely available on the web to allow stakeholders to explore the areas that have been surveyed. We hope the output of this investigation will support a dialogue between stakeholders in the sustainable management of the chalk reef.

Marine management in the UK is moving towards a more ecosystem-based, holistic approach that protects the whole environment while unsustainable or damaging activities are removed. This approach recognises people as integral components of ecosystems and socio-economic factors are considered with ecological factors. This benefits fisheries as it enables better management and protection of resources at the ecosystem level rather than at the species level (Gaines and others 2010).

7 References

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8 Appendices

Appendix I Features and Description of Cromer Shoal Chalk Beds MCZ from DSS

List of features (Designated Sites System 2020).

Site name:	Cromer Shoal Chalk Beds MCZ
Designation type:	MCZ
Site identification:	UKMCZ0031
Latest designation date:	29 January 2016
Designated features (click to see site specific description):	High energy circalittoral rock High energy infralittoral rock Moderate energy circalittoral rock Moderate energy infralittoral rock North Norfolk coast (Subtidal) Peat and clay exposures Subtidal chalk Subtidal coarse sediment Subtidal mixed sediments Subtidal sand
General information on the site features:	The general information on the designated features from the MCZ features catalogue is useful for understanding the designated features, and should be used in conjunction with the site specific information.
Designated area (ha):	32047.84
Overlapping Protected Areas:	Greater Wash SPA

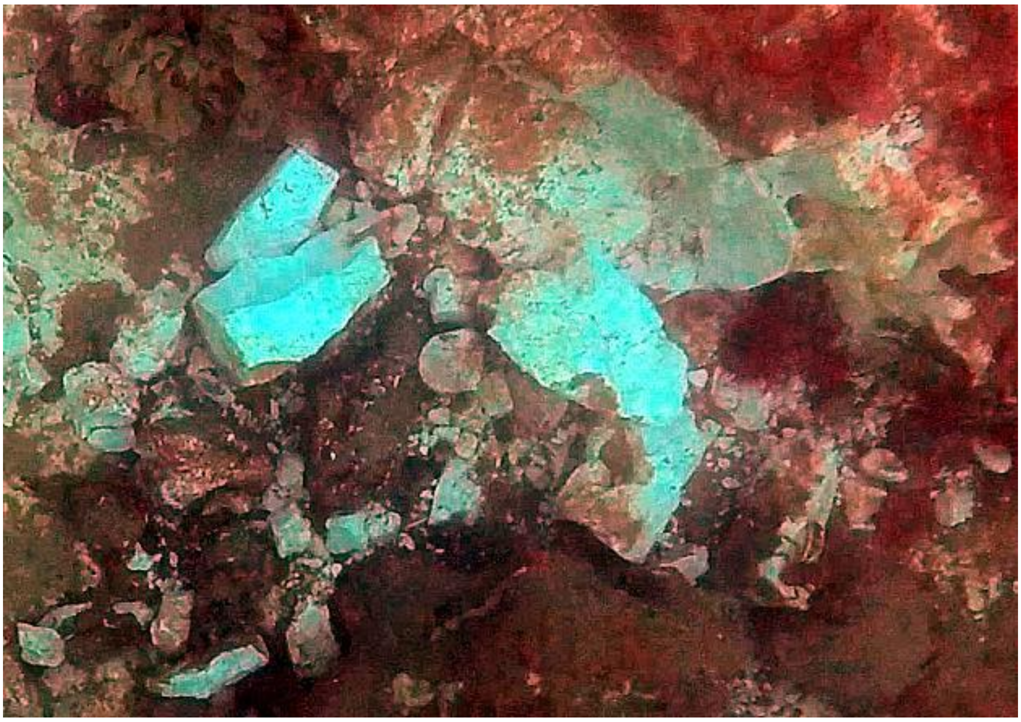
Appendix II Regulations relevant to trap fisheries targeting crustaceans in the EIFCA district

Source: Bridges, 2017

Regulation	Effect	Intent
MMO Vessel Licencing shellfish permit	Prohibits the fishing for shellfish without relevant permits	Limits entry into the fishery as no new permits are being issued.
Council Regulation 850/98 AN Natural England X XII for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms.	Prohibits landing of organisms below minimum legal landing sizes (115mm CW for brown crab, 87mm CL for European lobster)	Prevents removal of organisms from the fishery before reproductive maturity is reached.
Statutory instrument: Undersized Edible Crabs Order 2000 (2000 No 2029)	Increases MLS for brown crab (*Cancer pagurus*) to at least 130mm CW in areas outside of the Eastern Sea Fisheries Committee district.	Increases MLS for crab in areas outside of the EIFCA district while maintaining the lower 115mm CW EU MLS for the Norfolk population.
Lobster and Crawfish (Prohibition of Fishing and Landing) Order 2000 (as amended)	Prohibits fishing for, and landing of, lobsters and crawfish bearing a V notch or mutilated in such a manner as to obscure a V notch. As amended, prohibition of fishing and landing of berried lobsters and crawfish.	Protects brood stock that has been marked for protection using a V notch cut into the tail of the animal. As amended, protects brood stock from fishing and landing that are bearing eggs.
EIFCA Byelaw 5: - Prohibition on the use of edible crab (*C. pagurus*) for bait.	Prohibits the use of edible crab in any form (cooked or uncooked) as bait.	Prevents animals below MLS or of low value from being removed from the fishery without being landed.
EIFCA Byelaw 6: - Berried (egg-bearing) or soft shelled crab (*C. pagurus*) or lobster (*H. gammarus)*	Prohibits removal from the fishery any edible crab or lobster that is soft-shelled or bearing eggs.	Protection of current and future brood stock and prevention of poor practice in landing low quality catch.
EIFCA Byelaw 7: - Parts of shellfish	Prohibits landing of edible crab (*Cancer pagurus*), Velvet crab (*Necora puber*) or lobster (*Homarus gammarus*) or parts thereof which cannot be measured to ensure compliance with MLS.	Closes a loophole where parts of undersized animals could be landed potentially removing immature organisms from the fishery
EIFCA Byelaw 9: - Redeposition of shellfish	Requires that any shellfish, the removal of which is prohibited, be returned to the sea immediately and as near as possible in the place from which they were taken.	Ensures that organisms are returned the habitat from which they were taken, thus ensuring a greater chance of their survival on return to the sea.
EIFCA Byelaw 10: - Whitefooted edible crab	Prohibits the landing of 'whitefooted' crab (*Cancer pagurus*) between the 1st of November and the 30th of June.	Further prevents the landing of poor quality catch by prohibiting 'whitefooted' crabs which have not fully hardened from being landed.

Appendix III Photographic examples of damage

Strike

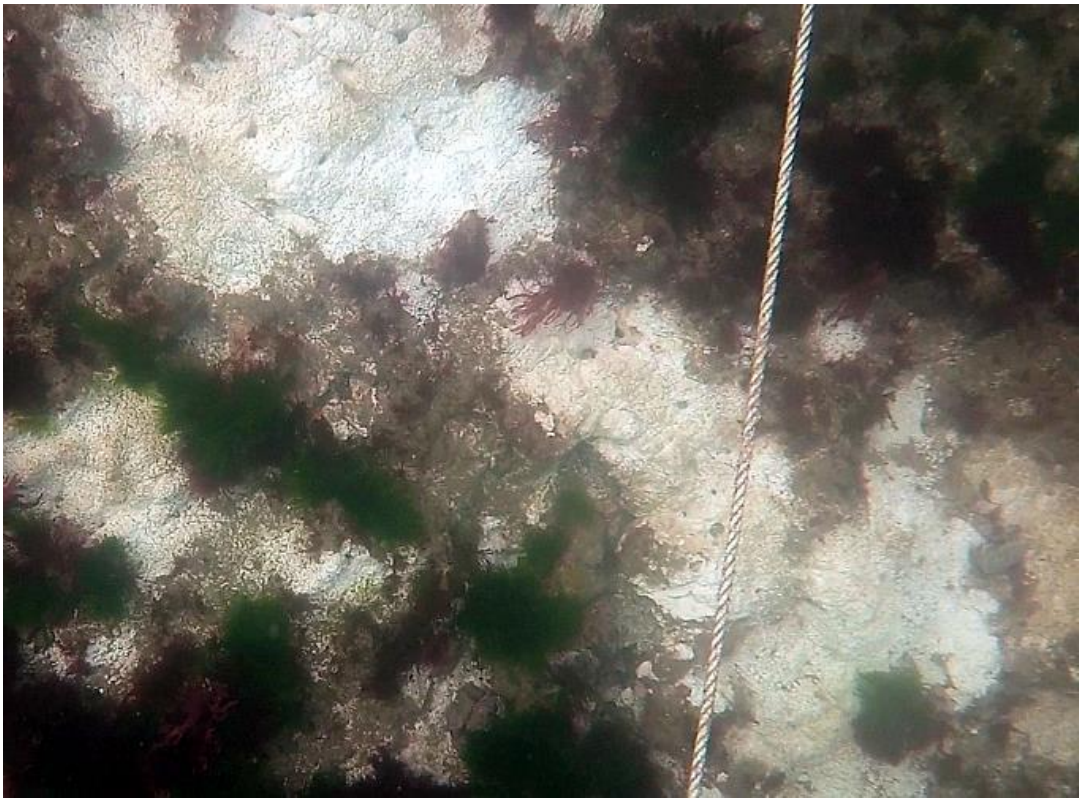


Drag

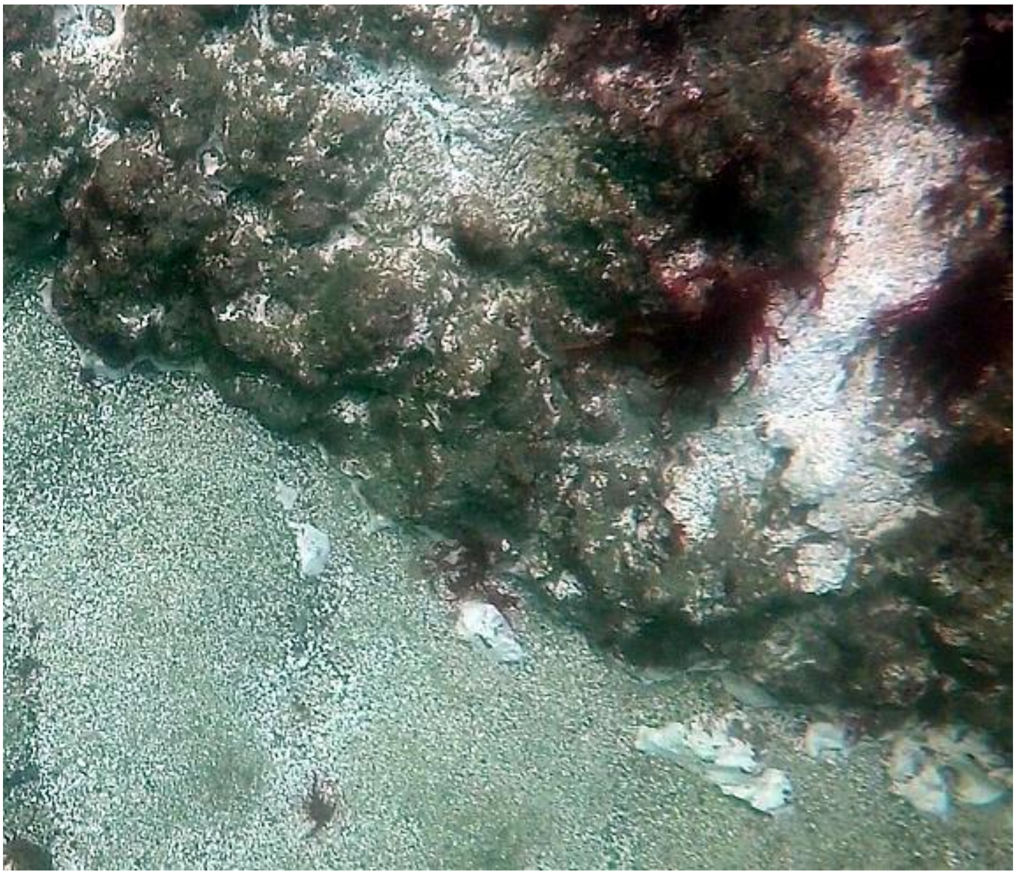
Lift

Abrasion (pot)

Abrasion (rope)

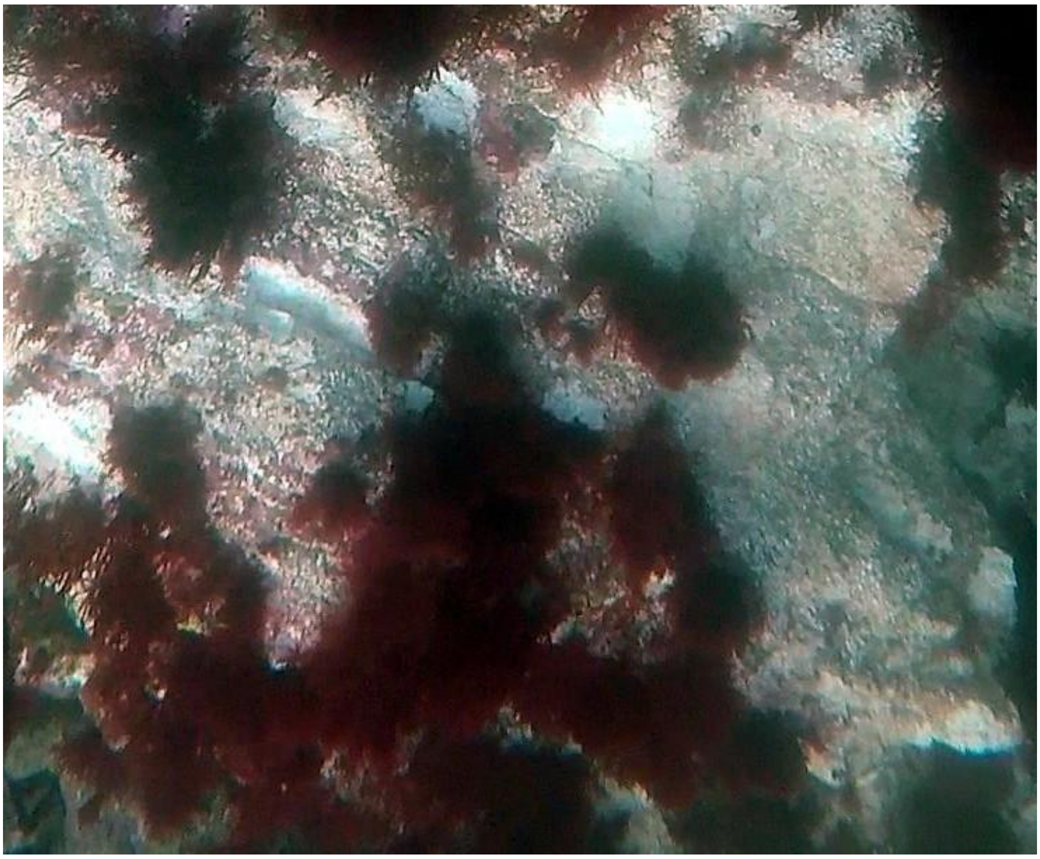


Grating



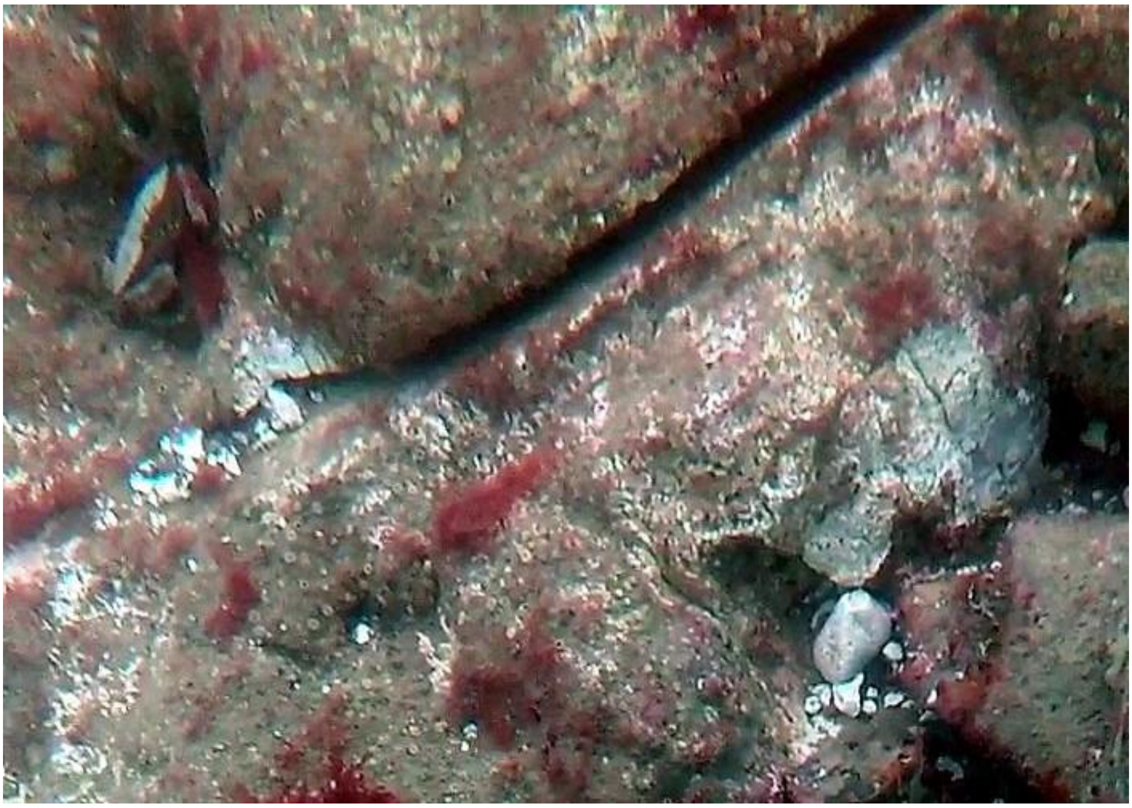
Angular Rubble

Burn



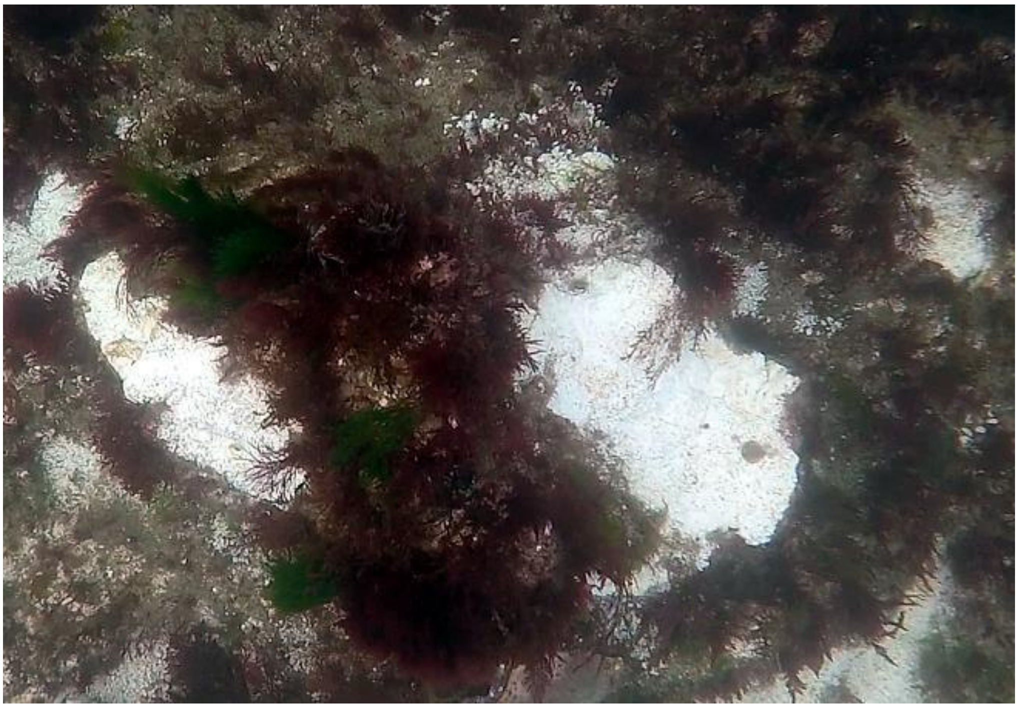
Saw

Cut



Level Shear

Unlevel Shear

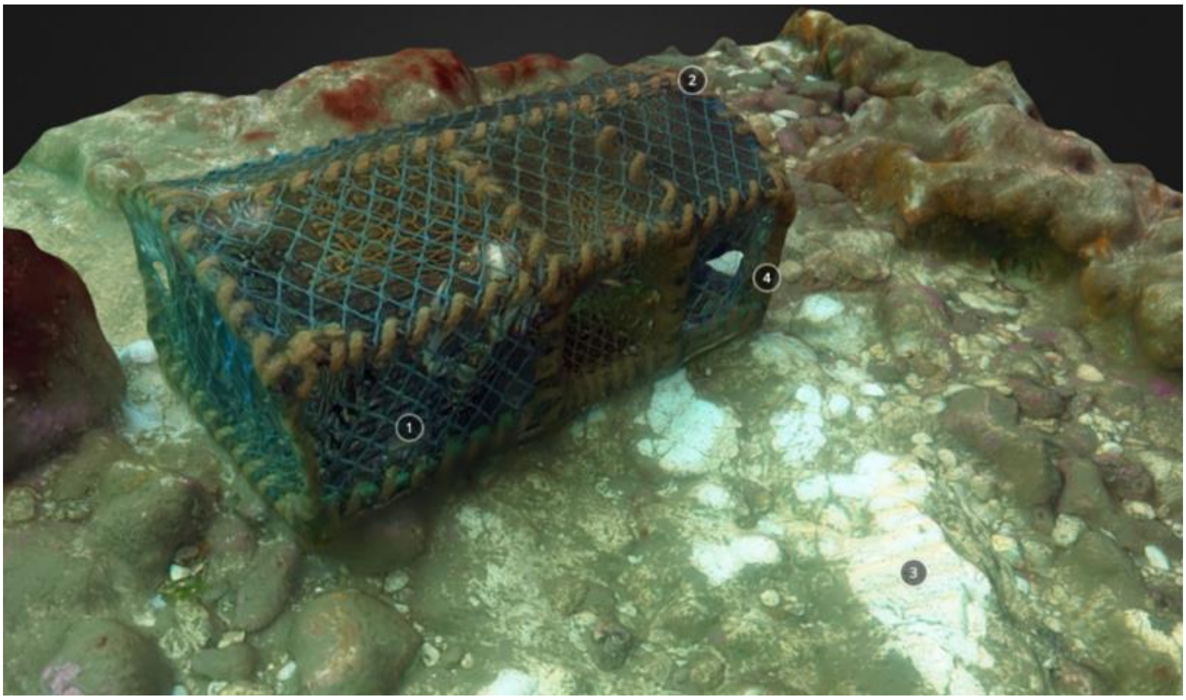


Appendix IV Resources and Data Archive

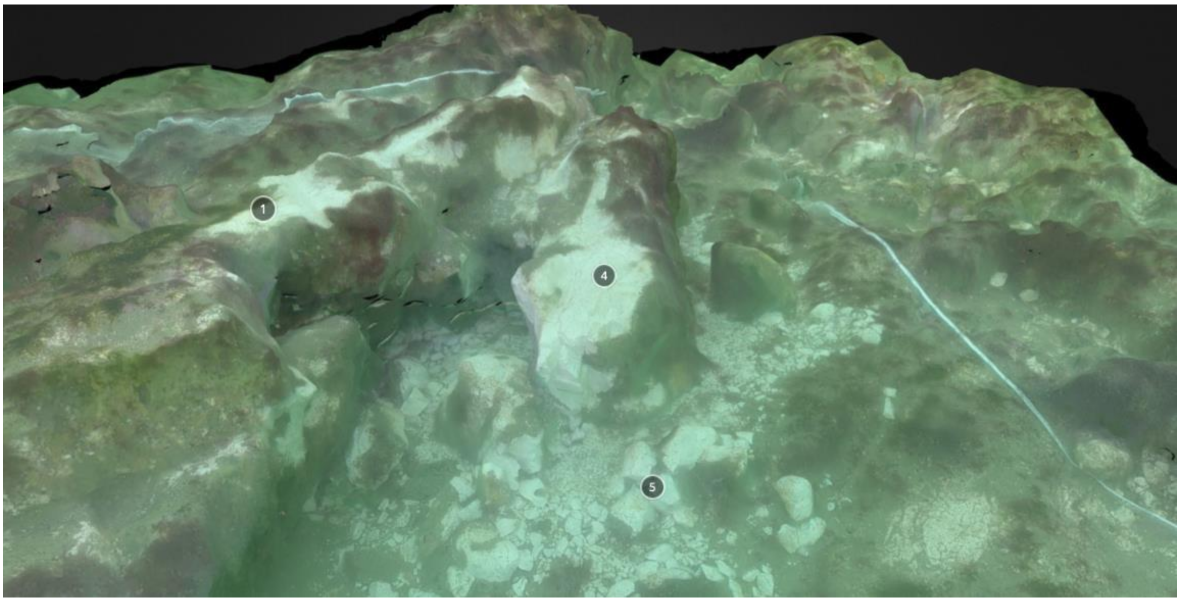
The following data is associated with this report.

Description	*Type*	*Size*	*Directory*
Photoscan models, source images and output model	.psx .jpg .obj	12.7 GB	/models/
Source camera footage, bio camera footage and extracted video stills	.mp4 .jpg	282 GB	/footage/
Data and charts	.xlsx	246 KB	/data/
Associated documents	.doc	9.2 MB	/documents/

In addition, the following resources are available online.



3D model of a traditional parlour pot on the chalk reef (Sheringham, July 2019). Source: https://skfb.ly/6MooN



3D models of recently impacted chalk (East Runton, July 2019). Source: https://skfb.ly/6LUSZ

Appendix V Biological Data Archive

Collated Biological Data.

1) Site Description- West Sheringham 500m from lifeboat slip.

Mixed sediment with cobbles, pebbles and very low lying reef. Common species included Metridium senile, hydroids, bryzoans including Bowebanki, like bottlebrush, sponges, sea squirts, encrusting algae, keel worms, wide type of Flustra, some thin red algae, tube worms, small Cancer pagurus and occasional slipper limpets.

Pots and Species Counts

				Dimensions cm.				Species Counts Crabs-			Lobsters			Bait			
Date	**Divers**	**Pots**	**Controls**	**Height**	**Width**	**Length**	**Aperture**	**Juveniles**	**Adults**	**Very large**	**Juveniles**	**Adults**	**Very large**	**Type**	**Quality**	**Bycatch**	**Type**
09/09/2019	Kevan Cook	1		45	45	91	15										
	Lucy May	2		42	45	90	13										
			1						1								
			2														

2) Site Description- Sheringham

Chalk bedrock ridges running north to south perpendicular to the shore, from 6m bsl at their base to 4m bsl at their peaks. The seabed in the channels between the ridges consisted of either coarse sand with deep waves or small boulders and cobbles, with some flint boulders present as well as chalk. All chalk was soft, i.e. could very easily be scratched using a plastic implement. Several signs of damage on the ridges, both in the vicinity of the pots and other areas, consisting of broken (clean white) surfaces often with fine chalk rubble in hollowed areas. Slipper limpet shells seen, but no live animals.

Pots and Species Counts

				Dimensions				Species Counts Crabs-			Lobsters			Bait			
Date	**Divers**	**Pots**	**Controls**	**Height**	**Width**	**Length**	**Aperture**	**Juveniles**	**Adults**	**Very large**	**Juveniles**	**Adults**	**Very large**	**Type**	**Quality**	**Bycatch**	**Type**
11/09/2019	Paula Lightfoot	1		40	46	90	20										
	Kevan Cook	2		36	46	92	25		1			1					
		3		38	47	92	27										
		4		41	46	90	27	1	1								
		5		41	45	92	27	14									
		6		40	45	93	25										
			1						1								
			2					1									
			3					3									
			4					1									
			5					4									

Note on internal aperture : In all cases, the aperture was arranged in the middle of one side of the pot and constructed by suspending two sheets of net horizontally between the two middle hoops of the pot such that there was a wide entrance leading to a very narrow exit in the pot. Therefore, the internal aperture measurement is that between the two supporting hoops. The internal horizontal gap, as visible from the outside, was minimal.

3) Site Description- West Runton (am)

Chalk bedrock gullies with flat bottomed sandy/gravel depressions. Chalk gullies run from north to south, 6.6 metres at the base and 4.5 metres at the peaks. Large amounts of cobble and pebbles present at base of gullies - presumably hard flint nodules from the chalk bedrock. Chalk bedrock was determined as soft rock and pebbles/cobbles as hard rock using in situ methods. Main bedrock reef bright white in appearance and comprised of mixed algae turf, mainly Plocamium spp., Dictyota dichotoma, Metacallophyllis lacinata and Vertebrata byssoides.

Pots and Species Counts								**Species Counts**									
				Dimensions				**Crabs-**			**Lobsters**			**Bait**			
Date	**Divers**	**Pots**	**Controls**	**Height**	**Width**	**Length**	**Apperture**	**Juveniles**	**Adults**	**Very large**	**Juveniles**	**Adults**	**Very large**	**Type**	**Quality**	**Bycatch**	**Type**
12/09/2019	Lucy May	1		40	45	96		1	5			8		Fish	Good - partly eaten but no obvious signs of decomposition	None	
	Trudy Russell	2		40	45	96		2	4		1	6		Fish	Good - partly eaten but no obvious signs of decomposition	None	
		3		40	45	96		2	2		1	5		Fish	Good - partly eaten but no obvious signs of decomposition	None	
		4		40	45	96		2	2		1	3		Fish	Good - partly eaten but no obvious signs of decomposition	None	
		5		40	45	96		1	2			2		Fish	Good - partly eaten but no obvious signs of decomposition	None	
			1					1									
			2														
			3					2									
			4					3									
			5														
			Quadrats														
			1														
			2					1			2						
			3					1									
			4					1	2								
			5					3									

Pot materials- metal with plastic coating with 2 entries and no escape hatches.

4) Site Description - East Runton (pm)

Mixed chalk bedrock and cobble/boulders. Very strong current, 7.1 metres max depth. Chalk bedrock gullies running from north to south, but much wider and flatter than other sites surveyed. Damage from potting gear visible, particularly at end of pot line (abrasion on top of gully). Juvenile Cancer pagurus particularly common on exposed/damaged chalk bedrock. (Please note - Go Pro ran out of memory so limited photos/video). Chalk bedrock was determined as soft rock and pebbles/cobbles as hard rock using in situ methods. Species community characterised by mixed red, green and brown algal turf, predominantly Heterosiphonia plumosa, Metacallophyllis lacinata and Plocamium sp.

Pots and Species Counts								**Species Counts**									
				Dimensions				**Crabs-**			**Lobsters**			**Bait**			
Date	**Divers**	**Pots**	**Controls**	**Height**	**Width**	**Length**	**Apperture**	**Juveniles**	**Adults**	**Very large**	**Juveniles**	**Adults**	**Very large**	**Type**	**Quality**	**Bycatch**	**Type**
12/09/2019	Lucy May	1		40	44	95	16	1	4			1		grayflesh	good, no signs of decomp.		
	Fiona Tibbitt	2		40	44	95	16	1			1					1	Nec. puber
		3		40	44	95	16		3	1							
		4		40	44	95	16	2	8			1				1	Nec. puber
		5		40	44	95	16										
			1					18									
			2					10	2								
			3					20	12								
			4														
			5														
			Quadrats														
			1					17				1					
			2					6	2		1						
			3					18	11		2	1					
			4														
			5														

Pot materials- metal with plastic coating & nylon rope. 2 entries and no escape hatches.

1)	**Date**	**Divers**	**Site**
	09/09/2019	**Lucy May and Kevan Cook**	**West Sheringham.**
	Phase 1 Survey		

Site Description:Mixed sediment with cobbles, pebbles and very low lying reef. Common species included Metridium senile, hydroids, bryzoans including Bowebanki, like bottlebrush, sponges, sea squirts, encrusting algae, keel worms, wide type of Flustra, some thin red algae, tube worms, small Cancer pagurus and occasional slipper limpets.

Family/ phyla	Species	SACFOR
Seaweeds	Heterosiphonia plumosa	F
	Metacallophyllis laciniata	O
	Calliblepharis ciliata	O
	Plocamium spp.	F
	Sciania furcellata	O
	Cladophora rupestris	O
	Dictyota dichotoma	O
	Vertebrata byssoides	O
Sponges	Amphilectus fucorum	O
	Hymedesmia sp	O
	Halichondria panacea	R
	Cliona celata (boring form)	O
Cnidarians	Urticina felina	O
	Sargartia elegans	R
Crustaceans	Galathea squamifera	O
	Cancer pagurus	F
	Homarus gammarus	O
	Necora puber	O

2)	**Date**	**Divers**	**Site**
	11/09/2019	**Paula Lightfoot and Kevan Cook**	**Sheringham.**
	Phase 1 Survey		

Species community characterised by mixed red, green and brown algal turf, predominantly Calliblepharus ciliata, Plocamium sp, Cladophora rupestris and Dictyota dichotoma, with patches of encrusting pink algae also frequent. Encrusting sponges also present both on boulders and bedrock, notably Amphilectus fucorum, Halichondria panacea and Hymedesmia sp (purple sponge). Many mobile species seen, notably Cancer pagurus and several fish species.

Family/ phyla	Species	SACFOR
Sponges	Amphilectus fucorum	O
	Halichondria panacea	O
	Hymedesmia sp (purple sponge)	O
	Dysidea fragilis	R
	Cliona sp (boring form)	O
Cnidarians	Urticina felina	F
	Sagartia elegans	O
Worms	Spirobranchus sp.	O
	Polydora sp. (locally common, i.e. covering whole boulders)	O

	Crustaceans	Homarus gammarus (both in pots and outside)	O											
		Cancer pagurus (both in pots and outside)	F											
		Necora puber	O											
		Inachus sp.	O											
		Cirripedia	O											
		Galathea squamifera	R											
	Molluscs	Tectura virginea	O											
		Steromphala cineraria	O											
		Calliostoma ziziphynum	R											
		Rissoa parva	A											
	Echinoderms	Asterias rubens	O											
	Sea squirts	Perophora listeri (attached to a red seaweed)	R											
		Didemnum maculosum var. dentata	R											
		Didemnid sea squirts indet	R											
		Morchellium argus	R											
	Fishes	Pholis gunnellus	R											
		Taurulus bubalis	R											
		Callionymus reticulatus	R											
		Labrus bergylta	O											
		Symphodus melops	O											
		Gobiusculus flavescens	F											
		Pomatoschistus sp	O											
	Seaweeds	Callophyllis laciniata	C											
		Plocamium sp.	C											
		Dictyota dichotoma	O											
		Heterosiphonia plumosa	O											
		Scinaia sp.	R											
		Halurus equisetifolius	R											
		Cladophora rupestris	F											
		Chondrus crispus	O											
		Ulva spp.	O											
		Ceramium sp.	O											
		Brongniartella byssoides	R											
		Hypoglossum hypoglossoides	R											
		Encrusting pink algae	F											
		Encrusting red algae	O											
		Cryptopleura ramosa	R											

3)	Date	Divers	Site
	12/09/2019	Trudy Russell and Lucy May	West Runton
	Phase 1 Survey		
	Chalk bedrock gullies with flat bottomed sandy/gravel depressions. Chalk gullies run from north to south, 6.6 metres at the base and 4.5 metres at the peaks. Large amounts of cobble and pebbles present at base of gullies - presumably hard flint nodules from the chalk bedrock. Chalk bedrock was determined as soft rock and pebbles/cobbles as hard rock using in situ methods. Main bedrock reef bright white in appearance and comprised of mixed algae turf, mainly Plocamium spp., Dictyota dichotoma, Metacallophyllis lacinata and Vertebrata byssoides.		
	Seaweeds	Heterosiphonia plumosa	F
		Metacallophyllis laciniata	O
		Calliblepharis ciliata	O
		Plocamium spp.	F
		Sciania furcellata	O
		Homarus gammarus	O
		Dictyota dichotoma	O
		Vertebrata byssoides	O
		Cladophora rupestris	O
	Crustaceans	Necora puber	O
		Galathea squamifera	O
		Cancer pagurus	F
	Cnidarians	Urticina felina	O
		Sargartia elegans	R
	Porifera	Hymedesmia sp	O
		Halichondria panacea	R
		Amphilectus fucorum	O
		Cliona cleata (boring form)	O
4)	Date	Divers	Site
	12/09/2019	Fiona Tibbitt and Lucy May	East Runton
	Phase 1 Survey		
	Mixed chalk bedrock and cobble/boulders. Very strong current, 7.1 metres max depth. Chalk bedrock gullies running from north to south, but much wider and flatter than other sites surveyed. Damage from potting gear visible, particularly at end of pot line (abrasion on top of gully). Juvenile Cancer pagurus particularly common on exposed/damaged chalk bedrock. (Please note - Go Pro ran out of memory so limited photos/video). Chalk bedrock was determined as soft rock and pebbles/cobbles as hard rock using in situ methods. Species community characterised by mixed red, green and brown algal turf, predominantly Heterosiphonia plumosa, Metacallophyllis lacinata and Plocamium sp.		
	Seaweeds	Heterosiphonia plumosa	F
		Metacallophyllis lacinata	F
		Calliblepharis cilliata	O
		Plocamium spp.	F
		Sciania furcellata	O
		Dictyota dichotoma	O
		Vertebrata byssoides	R
		Cladophora rupestris	R
		Urticina felina	O
	Crustaceans	Cancer pagurus	C
		Homarus gammarus	O
		Galathea squamifera	O
		Necora puber	O
	Cnidarians	Sargartia elegans	R
		Didemnid	O
	Porifera	Cliona cleata (boring form)	O
		Hymedesmia sp	R
		Halichondria panacea	O
		Amphilectus fucorum	O