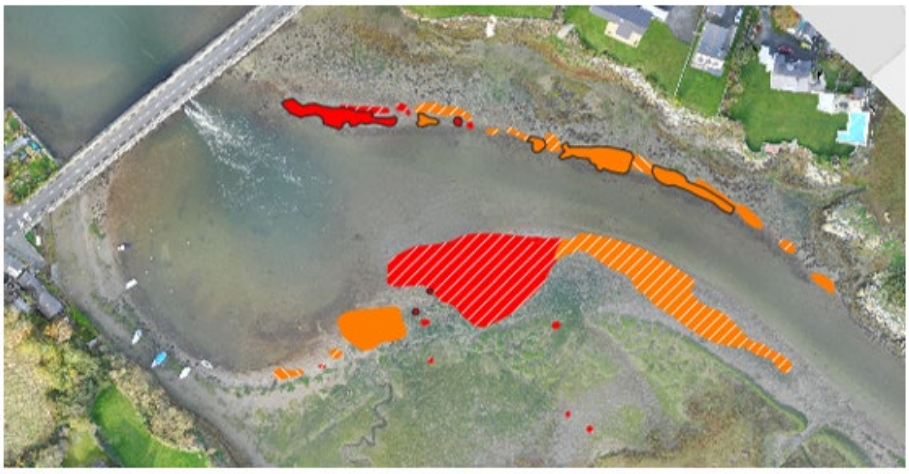
Cyfoeth Naturiol Cymru
Natural Resources Wales

Investigating the location and intensity of bait digging in Wales



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About Natural Resources Wales

Natural Resources Wales is the organisation responsible for the work carried out by the three former organisations, the Countryside Council for Wales, Environment Agency Wales and Forestry Commission Wales. It is also responsible for some functions previously undertaken by Welsh Government.

Our purpose is to ensure that the natural resources of Wales are sustainably maintained, used and enhanced, now and in the future.

We work for the communities of Wales to protect people and their homes as much as possible from environmental incidents like flooding and pollution. We provide opportunities for people to learn, use and benefit from Wales' natural resources.

We work to support Wales' economy by enabling the sustainable use of natural resources to support jobs and enterprise. We help businesses and developers to understand and consider environmental limits when they make important decisions.

We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

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Crynodeb Gweithredol

Mae gweithgarwch palu am abwyd yn broblem fawr ar lannau penodol yng Nghymru, yn enwedig lle mae swm y palu'n peri newidiadau a difrod hirdymor i gynefinoedd sensitif sy'n adfer yn araf.

Nod y prosiect hwn oedd pennu addasrwydd lluniau a dynnwyd o'r awyr gan Gerbydau Awyr Di-griw fel offeryn i archwilio graddfa ofodol a thymhorol gweithgarwch palu am abwyd ar safleoedd dethol yng Nghymru. Wrth wneud hyn, gwnaeth y prosiect hefyd roi cipolwg ar leoliad a lefel y gweithgarwch palu am abwyd ar safleoedd dethol rhwng hydref 2019 a dechrau gwanwyn 2020. Er efallai nad yw'r dulliau peilot hyn yn cynrychioli holl gwmpas y gwaith, mewn sawl achos, mae'r allbynnau'n cynrychioli'r dystiolaeth gyntaf a fapiwyd o weithgarwch palu am abwyd yn y lleoliadau hyn. Roedd y broses o amseru'r contract yn dibynnu ar y cyllid oedd ar gael a pharhaodd y contract o fis Medi 2019 tan fis Mawrth 2020.

Hedfanodd Cerbyd Awyr Di-griw dros 12 ardal (saith yng ngogledd Cymru, pedwar yn Aberdaugleddau a Bae Abertawe) a chynhyrchwyd ffotograffiaeth o'r awyr a gywirwyd (orthorectified). Yn ogystal, cynhaliwyd arolwg glannau ynghyd â chasglu gwybodaeth drwy arsylwi ar y ddaear a phalwyd tyllau rheoli i archwilio lefel y dystiolaeth o weithgarwch palu am abwyd ar lannau â nodweddion gwahanol. Ailymwelwyd â'r glannau i asesu lefel y tyllau treial dros amser i ddangos hirhoedledd y difrod gweladwy ar y glannau.

Pennwyd methodoleg ar gyfer digideiddio tystiolaeth o weithgarwch palu am abwyd gan ddefnyddio'r ffotograffiaeth o'r awyr a gasglwyd, wedi'i chefnogi gan yr wybodaeth a gasglwyd drwy arsylwi ar y ddaear yn ystod ymweliadau safle. Cafodd yr ardaloedd a oedd yn dangos tystiolaeth o weithgarwch palu am abwyd eu polygoneiddio a rhoddwyd gwerth arwynebedd (m^2), i'r polygonau hyn, cawsant eu categoreiddio fel rhai newydd neu hen, rhoddwyd lefel o ddwysedd palu iddynt ynghyd â lefel hyder ar gyfer yr asesiad.

Canfyddiadau allweddol

Methodoleg a chyflwyno data

- Mae lluniau o'r awyr wedi'u tynnu gan Gerbyd Awyr Di-griw yn ddull gwerthfawr o gofnodi ardaloedd mawr o lannau i'w prosesu'n ddiweddarach. Fodd bynnag, mae cyfyngiadau penodol i'r broses o dynnu lluniau o'r awyr gan ddefnyddio Cerbyd Awyr Di-griw; tywydd sych, lefelau golau digonol a chyflymder gwynt isel.
- Roedd gweithio gyda chyfnodau o orllanw isel yn y gaeaf (yn enwedig yng ngogledd Cymru) yn peri heriau sylweddol. Felly, dylai unrhyw arolygon yn y dyfodol gael eu cynnal yn ystod yr haf pan fo modd disgwyl tywydd gwell a mwy o oriau o olau dydd. Mae'n debygol mewn rhai lleoliadau y gallai fod mwy o weithgarwch palu am abwyd yn ystod misoedd yr haf os yw abwyd yn cael ei gasglu ar gyfer y farchnad ymwelwyr.

- Gall lleoliadau sy'n destun cyfyngiadau'r Awdurdod Hedfan Sifil (ger meysydd glanio) beri cymhlethdodau sylweddol o ran logisteg wrth wneud gwaith arolygu gan ddefnyddio Cerbydau Awyr Di-griw. Gall hyn gael ei wella'n rhannol wrth i wneuthurwyr wella dulliau o ddiddymu geoffensio â chaniatâd. Efallai y bydd safleoedd a nodir ar gyfer eu harolygu yn y dyfodol mewn ardaloedd gofod awyr cyfyngedig yn gofyn am amser arwain hirach ar gyfer cynllunio arolwg a/neu gynnal arolwg ar droed yn lle.
- Dangoswyd bod dŵr ffo ar draeth yn cuddio tystiolaeth o weithgarwch palu am abwyd ar ffotograffau o'r awyr. Dylid ystyried hyn wrth asesu ai drôn yw'r dull mwyaf priodol o fapio gweithgarwch palu am abwyd ar y safleoedd hyn.
- Dangoswyd bod Modelau Tirwedd Lleol (LRMs) a Modelau Tirwedd Cysgodol (SRMs) yn nodi'n glir y gwahaniaethau bach mewn uchder yn lleol ar y lan ond na allent wahaniaethu'n glir rhwng gweithgarwch palu am abwyd a nodweddion eraill ar y lan. Gellir ystyried astudiaeth benodol fach ar y defnydd o'r modelau hyn ar gyfer gwaith yn y dyfodol, ac er y byddai'n ddrud, gallai fod yn ddull defnyddiol o fapio gweithgarwch palu am abwyd ar rai safleoedd.
- Nid oedd y contract cyfredol yn caniatáu hediadau mynych. Mae hyn yn angenrheidiol er mwyn gallu pennu cyfres hwy o amser a byddai hyn yn bwysig er mwyn creu darlun o'r effaith ar safle.
- Dangoswyd mai prin iawn o weithgarwch palu am abwyd a ddangoswyd gan y defnydd o ffotograffiaeth o'r awyr i fapio gwaith palu am abwyd ar lannau tywodlyd symudol. Dylai arolygon yn y dyfodol gan ddefnyddio Cerbydau Awyr Di-griw ganolbwyntio ar lannau lle mae'r is-haen yn ei gwneud yn bosibl sicrhau hirhoedledd tyllau palu am abwyd.
- Nodwyd bod y gwaith o gasglu gwybodaeth drwy arsylwi ar y ddaear yn elfen bwysig o fapio gweithgarwch palu am abwyd oherwydd nad yw mapio difrod o ffotograffau o'r awyr yn unig mor gadarn â chyfuniad o'r ddau ddull. Dylai gwaith yn y dyfodol ystyried defnyddio cyfuniad o ffotograffau o'r awyr ac arolwg o'r glannau i lunio mapiau mwy cywir a gwella hyder y ffotograffau.
- Prin oedd y dystiolaeth o weithgarwch palu am abwyd a gofnodwyd ar y glannau isaf, ac roedd hynny fwy na thebyg oherwydd nad oedd yr ardaloedd hyn yn cael eu datgelu'n aml iawn, sy'n awgrymu y gallai arolygon yn y dyfodol fanteisio ar amrywiaeth ehangach o lanwau.
- Nid oedd y mapiau palu am abwyd a gynhyrchwyd yn dangos cyfran fawr o balu 'dwysedd uchel'. Er y gallai hyn roi darlun cywir o ddwysedd y palu ar y safle, dylid ystyried a ellid addasu graddfa'r dwysedd ymhellach i nodi gwahaniaethau o ran dwysedd gweithgarwch yn y safleoedd hyn a rhyngddynt.
- Dylid ystyried a allai unrhyw addasiadau neu ddiwygiadau gael eu gwneud i'r dull o gynrychioli'r ardaloedd palu am abwyd ar safleoedd, i sicrhau bod yr ardaloedd y mae gweithgarwch palu am abwyd yn effeithio arnynt yn cael eu dangos mor glir a chyson â phosib rhwng safleoedd.

Arsylwi ar effeithiau gweithgarwch palu am abwyd a lefel y difrod ar safleoedd

- Gwelwyd tystiolaeth o weithgarwch palu am abwyd ar yr holl safleoedd a arolygwyd, yr ystyrir eu bod yn cynrychioli'r ardaloedd sydd wedi cael eu palu fwyaf y mae Cyfoeth Naturiol Cymru yn ymwybodol ohonynt yng Nghymru ar hyn o bryd.
- Ymddengys fod lefel uwch o weithgarwch palu am abwyd mewn ardaloedd â mynediad haws a lle i barcio.
- Mae effeithiau gweithgarwch palu am abwyd wedi cael eu nodi mewn cynefinoedd sydd wedi'u rhestru dan Adran 7 Deddf yr Amgylchedd (Cymru), sy'n cynnwys *Zostera notlii* (morwellt), graean mwdlyd cysgodol a gwastadeddau llaid a gwastadeddau tywod rhynglanwol.
- Cofnodwyd cyfanswm o 137.9 ha (o bob oedran a hyder) o waddod palu abwyd ar y 12 o safleoedd. Y safle â'r swm arwynebedd mwyaf o waith palu oedd 33.5 ha ar aber afon Foryd (er bod llawer o'r ardal y nodwyd ei bod yn cael ei phalu am abwyd o hyder isel). Y safle â'r arwynebedd lleiaf a gofnodwyd oedd Bae Gelliswick yn Sir Benfro, gyda'r palu dwys amlwg yn digwydd mewn un ardal leol yn unig.
- Cofnodwyd tystiolaeth o balu diweddar ar yr holl safleoedd ac eithrio Traeth Pen-rhos ar Ynys Môn.
- Cofnodwyd bod palwyr abwyd yn palu'n weithredol ar saith o'r 12 o safleoedd ar adeg yr ymweliad.
- Nodwyd yn yr arolwg hwn bod gweithgarwch palu am abwyd wedi cael sawl effaith ar y glannau a arolygwyd. Mae'r rhain yn cynnwys:
    - Cerrig crynion rhannol symudol â gwymon yn cael ei ddal mewn tyllau abwyd sydd â'r potensial i newid y cynefin. Byddai o ddiddordeb i gynnal mwy o astudiaethau ar hyn.
    - Tyllau sy'n llenwi â gwaddod meddal, sy'n arwain at gyfres o bantiau ar waddod mwy meddal ac yna'r glannau amgylchynol.
    - Graean sy'n dod i wyneb y lan oherwydd y gwaith palu, gan greu tirwedd raeanog a thyllog artiffisial.
- Roedd lefel y dystiolaeth o weithgarwch palu am abwyd yn amrywio o lan i lan. Roedd difrod gweladwy'n para hwyaf ar lannau a oedd yn gysgodol/cysgodol iawn, ac roedd y tyllau'n parhau i fod yn weladwy iawn ar rai o'r safleoedd mwdlyd a graeanog hyn ar ôl oddeutu pedwar mis.
- Roedd y difrod gweladwy'n diflannu gyflymaf ar lannau a oedd yn cynnwys tywod/tywod bras ac yn fwy agored, gyda thyllau'n diflannu mewn diwrnod neu ddau.

- Ystyriwyd bod gaeaf 2019/2020 yn hynod stormus ac roedd yn debygol ei fod wedi arwain at donnau mwy na'r arfer ar rai safleoedd gan lyfnhau cynefinoedd a fyddai fel arall yn gysgodol mewn ffordd anarferol.

Argymhellion ar gyfer astudiaethau yn y dyfodol i gael gwell dealltwriaeth o ddosbarthiad ac effeithiau gweithgarwch palu am abwyd yng Nghymru.

- Byddai mwy o astudiaethau annibynnol ar bwysigrwydd y difrod a achosir ar lannau sydd â thonau a mathau o waddod gwahanol, yn esbonio a oes angen mwy o astudiaethau. Byddai'n ddefnyddiol cadarnhau natur tymor byr yr aflonyddu ar waddod a'r adferiad ecolegol ar safleoedd mwy tywodlyd, sy'n cael eu datgelu'n fwy i donnau.
- Mwy o ddefnydd o'r Cerbyd Awyr Di-griw (ynghyd â lefel o gasglu gwybodaeth drwy arsylwi ar y ddaear), yn ystod misoedd yr haf, i gadarnhau effeithiolrwydd y dull hwn i fapio gweithgarwch palu am abwyd, yn ogystal ag ehangu ein dealltwriaeth o lefelau dwysedd gweithgarwch palu am abwyd ar safleoedd sydd wedi'u cysgodi rhag tonnau, lle gwyddys bod tyllau'n bodoli o hyd. Byddai mesuriad gwell o bresenoldeb tyllau, y tu allan i ddigwyddiadau storm a glaw eithafol, ar safleoedd sydd wedi'u cysgodi rhag tonnau hefyd yn werthfawr.
- Byddai mwy o arsylwadau ar achosion a mynychder cerrig crynion a chlogfeini rhannol symudol wedi'u gorchuddio â gwymon yn glanio ar dyllau abwyd, gan ddylanwadu ar adferiad safle oherwydd palu am abwyd yn fanteisiol. Mae gan y gweithgarwch hwn y potensial i achosi newidiadau hirdymor yn y cynefin. Gallai hyn fod yn addas ar gyfer prosiect anrhydedd neu ran o brosiect meistr.
- Gallai astudiaeth benodol bellach o'r defnydd o Fodelau Arwynebedd Digidol fod yn fanteisiol oherwydd bod potensial y gallant fod yn ddefnyddiol wrth fapio gweithgarwch palu am abwyd ar ardaloedd mawr o'r lan. Dylai astudiaethau gael eu gwneud mewn ardal arwahanol ag ychydig o ddŵr wyneb a phalu diweddar i brofi dulliau.
- Dylid ystyried a yw'r safleoedd dethol hyn yn cynrychioli'r ardaloedd palu am abwyd yr effeithir arnynt fwyaf neu a ddylai safleoedd ychwanegol yng Nghymru gael eu harolygu yn y dyfodol.
- Nid oedd y berthynas rhwng cystadlaethau palu a genweirio wedi cael ei hystyried yn ystod yr astudiaeth hon; gallai digwyddiadau penodol arwain at weithgarwch casglu ar raddfa fawr mewn lleoliadau penodol ac ar adegau penodol a byddai modd ymchwilio i hyn ymhellach.
- Gall canlyniadau'r astudiaeth hon gael eu defnyddio i helpu i flaenoriaethu'r safleoedd hynny sy'n dioddef y lefel uchaf o weithgarwch palu am abwyd er mwyn ymchwilio yn y dyfodol neu'r safleoedd sydd wedi'u difrodi fwyaf yn seiliedig ar y cynefinoedd sy'n bresennol.
- Mae'r astudiaeth hon yn rhoi tystiolaeth bwysig i hwyluso'r gwaith o reoli safleoedd lle ceir gweithgarwch palu am abwyd yn y dyfodol yng Nghymru.

Executive Summary

Bait digging is a particular problem on certain shores in Wales, especially where the volume of digging is causing long term changes and damage to sensitive habitats which are slow to recover.

The aim of this project was to establish the suitability of aerial imagery taken from Unmanned Aerial Vehicles (UAVs) as a tool to investigate the spatial and temporal extent of bait digging at selected sites in Wales. In doing this, the project also provided a snapshot of the location and intensity of bait digging at selected priority sites in Autumn 2019 – Early Spring 2020. Whilst these pilot methods may not represent complete coverage, in many cases the outputs represent the first mapped evidence of bait digging at these locations. The timing of the contract was determined by funding availability and ran from September 2019 to March 2020.

Twelve areas (seven in North Wales, four in Milford Haven and Swansea Bay) were overflown by a UAV and ortho rectified aerial photography produced. In addition, shore survey and ground truthing was undertaken, and control holes dug to investigate the persistence of bait digging evidence on shores with different characteristics. The shores were revisited to assess persistence of trial holes over time to indicate the longevity of visible damage on the shores.

A methodology was established for digitising bait digging evidence using the aerial photography collected, supported by ground truthing during site visits. Areas showing evidence of bait digging were polygonised and these polygons given an area value (m^2), categorised as new or old, assigned a level of digging intensity and given a confidence level for the assessment.

Key findings

Methodology and data presentation

- Aerial imagery taken from a UAV is a valuable tool for capturing large areas of shore for later processing. However, capturing aerial images using a UAV does have specific limitations; dry weather, adequate light levels and low windspeed.
- Working at spring low water in winter (especially in North Wales) posed significant challenges. Any future surveys should, in addition, be carried out during the summer when better weather and longer daylight can be expected. It is likely in some locations there could be more bait digging activity during summer months if bait is collected for the visitor market.
- Locations with Civil Aviation Authority flying restrictions (near airfields) can cause significant logistical complications when surveying using UAVs. This may be partially improved when manufacturers improve approaches to remove geo fencing with permission. Future areas identified to be surveyed in areas of restricted airspace may need a longer lead in time for survey planning and / or survey on foot instead.

- Water run off on a beach has been shown to obscure evidence of bait digging on aerial imagery. This should be considered when assessing whether a drone is the most appropriate method of mapping bait digging at these sites.
- Local Relief Models (LRMs) and Shaded Relief Models (SRMs) were shown to clearly identify small localised height differences on a shore but could not accurately distinguish between bait digging and other shore features. A small specific study on the use of these models could be considered for future work, as although expensive, could prove a useful method of mapping bait digging at some sites.
- The current contract did not allow for frequent flights to be made. This is needed for a longer time series to be established and would be important for building up a picture of the impact at a site.
- Using aerial photography to map bait digging on mobile sandy shores was shown to capture very little digging activity. Future survey using UAVs should focus on shores where the substratum allows for longevity of bait digging holes.
- Ground-truthing was identified as an important element of mapping bait digging as mapping damage from aerial imagery alone is not as robust as a combination of the two methods. Future work should consider using a combination of aerial imagery and shore survey to produce more accurate maps and improve the confidence of the imagery.
- Little evidence of bait digging was recorded on the extreme lower shore, likely to be due the reduced times that these areas are exposed, which suggests future surveys could take advantage of a wider range of tides.
- Maps of bait digging produced did not display a large proportion of ‘high’ intensity’ digging. While this may accurately represent the intensity of the digging at the site, it should be considered whether the scale of intensity could be adjusted to further identify differences in activity intensity within and between sites.
- It should be considered whether any adjustments or modifications could be made to the method of representing the areas of bait digging at sites, to ensure that the areas impacted by bait digging are displayed as clearly and consistently as possible between sites.

Site observation of bait digging impacts and persistence of damage

- Bait digging evidence was found at all of the sites surveyed, which are considered to represent the most heavily dug areas that NRW are currently aware of in Wales.
- Bait digging appeared to be more intense in areas with easier access and parking.

- Impacts of bait digging have been noted in habitats which are listed under Section 7 (of the Environment (Wales) Act 2016, which include *Zostera notlii* (Seagrass), Sheltered Muddy Gravels and Intertidal Mudflats and Sandflats.
- A total of 137.9 ha (all ages and confidences) of bait dug sediment was recorded at the 12 sites. The site with the greatest total area of digging was 33.5 ha on Y Foryd Estuary (although much of the area identified as bait dug was of low confidence). The site with the smallest recorded area was Gelliswick Bay in Pembrokeshire, with evident intense digging concentrated in a localised area.
- Evidence of recent digging was recorded at all of the sites except Penrhos Beach, Anglesey.
- Bait diggers were recorded actively digging at 7 of the 12 sites at the time of the visit.
- Bait digging has been noted in this survey to cause a number of impacts to the shores surveyed. These include;
    - Semi-mobile cobbles with seaweed getting 'caught' in bait holes and which has the potential to change the habitat. It would be of interest to carry out further studies on this.
    - Holes filling with soft sediment, leading to a series of depressions of softer sediment then the surrounding shore.
    - Gravel being brought up to the surface of the shore from the act of digging, creating artificially gravelly and cratered landscape.
- Persistence of bait digging evidence varied from shore to shore. Visible damage lasted longest at shores which were sheltered / extremely sheltered, and holes remained clearly visible at some of these muddy and gravelly sites after approximately 4 months.
- Visible damage disappeared most quickly on shores which were composed of sand / coarse sand and were more exposed, with holes disappearing in a day or two.
- The winter of 2019/20 was considered exceptionally stormy and was likely to have resulted in greater than normal wave action on some sites and resulted in unusual smoothing of otherwise sheltered habitats.

Recommendations for future studies to better understand distribution and impacts of bait digging in Wales

- Further independent studies on the significance of damage caused on shores of different wave exposures and sediment types, would elucidate whether further studies are necessary. It would be useful to confirm the short term nature of

sediment disturbance and ecological recovery in sandier, more wave exposed sites.

- Further use of the UAV (accompanied by a level of ground truthing), during summer months, to confirm the effectiveness of this method to map bait digging, as well as extend our understanding of levels of bait digging intensity on wave sheltered sites, where holes are known to persist. A better measure of hole persistence, outside of extreme storm and rainfall events, on the wave sheltered sites would also be valuable.
- Further observations on the occurrence and frequency of semi-mobile, seaweed covered cobbles and boulders landing in bait holes, influencing site recovery from bait digging, would be beneficial. This activity has the potential to cause long term changes in habitat. This may suit an honours or part of a master's project.
- A further specific study on the use of the use of Digital Surface Models may be beneficial as there is the potential that they may be useful in mapping bait digging on large areas of the shore. Studies should be undertaken in a discrete area with little surface water and recent digging to test methods.
- It should be considered whether these selected sites represent the most impacted areas of bait digging or whether additional sites in Wales should be surveyed in future.
- The relationship between digging and angling competitions was not taken into account during this study; specific events could lead to large scale collection at certain locations at certain times could be further investigated.
- The results of this study can be used to help prioritise those sites that suffer the most extensive bait digging for future investigation or are the most damaged based on the habitats which are present.
- This study provides important evidence required to inform possible future management of sites to the activity of bait digging in Wales.

1. Introduction

The aim of the project was to establish the suitability of aerial imagery taken from Unmanned Aerial Vehicles (UAV) / drones, to investigate the spatial and temporal extent of bait digging. In doing this, the project also aimed to provide a snapshot of the location of bait digging at these selected priority sites in Autumn 2019 – early Spring 2020. Whilst these pilot methods may not represent complete coverage, in many cases the outputs represent the first mapped evidence of bait digging at these locations. The timing of the project was determined by funding availability and ran from September 2019 to March 2020.

2. Methodology

A UAV was flown over each site to capture orthorectified imagery, from which a digitised layer of bait digging activity was derived. The intention was to fly each site twice to investigate changes over time, but this was not possible due to limitations of poor weather and low tide times.

Control holes were dug and ground truthing undertaken near the vicinity of these holes whilst the UAV flights were undertaken.

2.1 Equipment

A fixed wing UAV was used to fly the sites to capture aerial imagery at spring low water when the bait digging areas were considered to be fully exposed. Fixed wing UAVs can fly further, stay up for longer and cover larger areas more quickly when compared to traditional quadcopter drones.

The UAV used was a Sensefly eBee Plus (https://www.sensefly.com/drone/ebee-plus-survey-drone/). This is a professional survey grade UAV with Real-Time kinematic (RTK)/ Post-processed kinematic (PPK) functionality. It has a cruise speed: 40-110 km/h and absolute horizontal/vertical accuracy (w/GCPs) down to 3 cm (1.2 in). The camera has a 1” sensor RGB, (20 megapixel) – model S.O.D.A._10.6_5472x3648 (RGB).

The UAV was flown at a height of 120 m which with the attached camera equates one pixel to approximately 3 cm on the ground. The UAV can be flown lower to increase the pixel size but (especially in poor light) this results in lower quality images due to “ground rush”. This is when the ground underneath is moving so fast the camera image starts to blur.

A secondary drone (a DJI Phantom 4 Pro Plus) was used over the Cob area of Beddmanarch Bay because the area was large and the UAV could not cover all the areas in the tidal and light window available. This carries a camera with a 1” COS giving 20 million pixels. The lens is FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m. The DHI Phantom was test flown to match the resolution to the UAV so that the images could be processed alongside those captured by the UAV.

2.2 Flight planning

GIS polygons of the sites to survey were supplied by NRW. The flight path of the UAV was planned to comply with CAA regulations and to prioritise the lower shore areas as close to low water as possible.

The flight plan was designed using eMotion3 software and then uploaded to the UAV and the plane launched. Overlapping images of the shore were taken. Two thirds of each image is overlapped with neighbouring images allowing the Pix4DMapper software to image match adjacent photographs and so derive the Digital Surface Model. A buffer was applied to the NRW supplied boundaries to make sure there was sufficient overlap. Therefore in some cases the aerial imagery supplied will cover a slightly larger area than that specified by NRW.

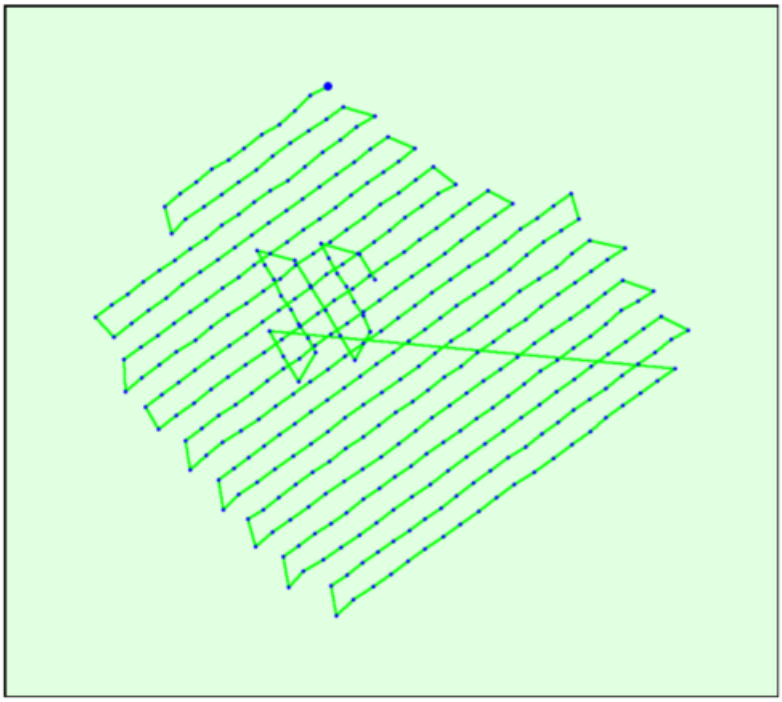


Figure 1 - Flight plan and image locations for Gann as an example

2.2.1 Areas surveyed

There were initially 13 sites listed to be surveyed. However, NRW considered that Pembroke Ferry in Milford Haven, which only had a very old report of bait digging, had substrate that was now generally too stony to be dug regularly and was excluded from the contract, leaving 12 distinct sites to be surveyed, see Table 1.

Table 1 - Sites surveyed

Site name	North or South Wales	Approximate area of the site
Between Beaumaris and Penmon, Menai Strait	North	176 ha
Penrhos Beach, Holyhead	North	37 ha

Site name	North or South Wales	Approximate area of the site
Beddmanarch Bay, Holyhead	North	336 ha
Four Mile Bridge, Cymyran Strait.	North	4 ha
Llanfair yn Neubwll, Cymyran Strait.	North	9 ha
Inland Sea, Cymyran Strait.	North	8 ha
Y Foryd Estuary, Menai Strait	North	145 ha
Gann Flats, Milford Haven	South	42 ha
Sandy Haven, Milford Haven	South	22 ha (Pill) and 24 ha (beach)
Gelliswick Bay, Milford Haven	South	56 ha
Angle Bay, Milford Haven	South	62 ha
Swansea Bay	South	474 ha (flown)

2.3 Challenges

The Civil Aviation Authority (CAA) regulations have strict rules as to how a drone can be flown (e.g. how far from the pilot it can operate). Some of the areas on Anglesey are within the “no fly” area of RAF Valley airfield and so special permission must be sought (normally only granted at weekends).

This has become even stricter since new laws were introduced part way through the project (30th November 2019) following the drone attacks on London airports. Drone manufacturers now program “no fly” areas into their software making it physically impossible to take off or enter controlled airspace. The DJI Phantom’s software was updated immediately, the eBeePlus has yet to implement the geofence (so could be flown with permission).

The process to get permission to override a geofence is still in its infancy, but it now means that acquiring permission from RAF Valley is not sufficient. Proof of this permission has to be sent to the drone manufacturer who then allows you to unlock that particular bit of airspace. To date we have had no response to our applications. This impacted the areas around the Inland Sea and Cymyran Strait, meaning that the DJI Phantom could not be flown in this area.

Geofenced no fly areas can be viewed here - https://www.dji.com/uk/flysafe/geo-map.

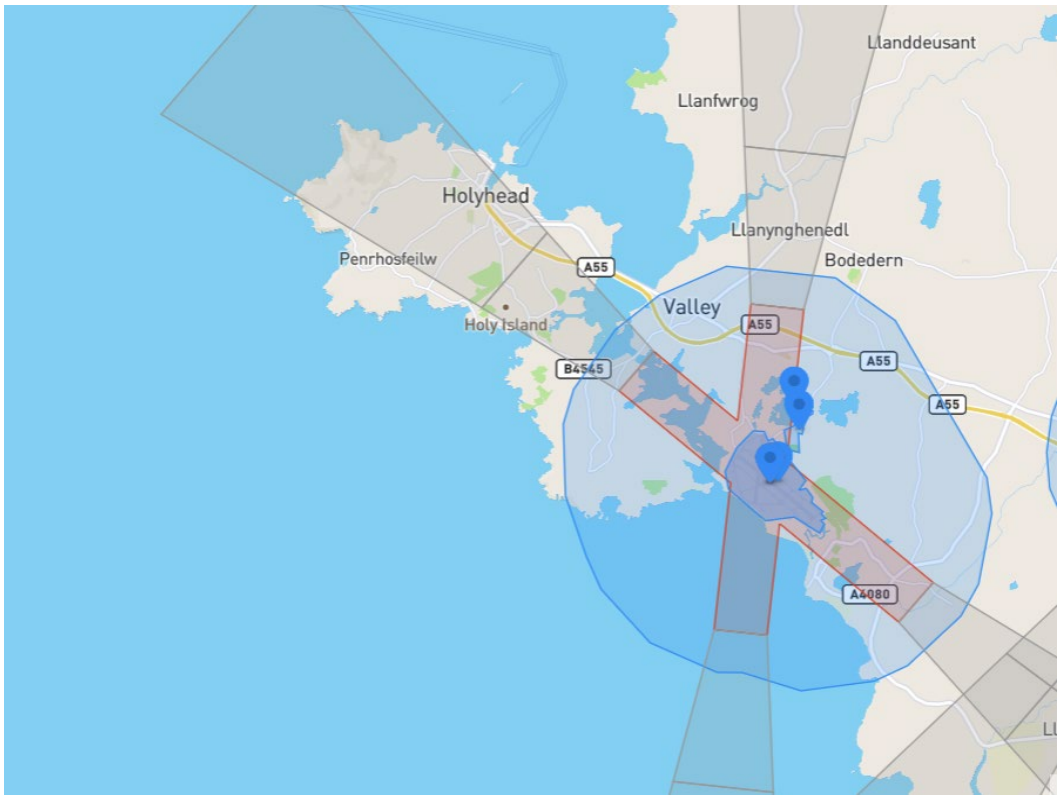


Figure 2 - No Fly GeoZones around Valley airfield. DJI phantom will not fly or take off in the red zones. Blue pins give contact details for relevant authority.

In order to be confident that the bait digging areas are exposed, survey during spring tides is needed. Reasonable light conditions are also required; if it is too dark or wet the imagery will not be clear. The UAV also cannot fly in strong winds.

The project took place between September 2019 and March 2020. This provided significant challenges as the tidal cycles in north Wales are such that spring tides are early in the morning and late in the afternoon, so for a significant period of the project there were no suitable spring tides occurring with sufficient daylight.

In addition, a typical winter weather pattern with equinoctial gales and a succession of lows sweeping in from the Atlantic Ocean meant that several spring tidal cycles were unavailable for survey, which included the opportunity for the second set of flights. Named storms are shown in Table 2, in addition to many additional days of strong winds.

Table 2 – UK storm systems, winter 2019 / 2020

Name	Date named
Atiyah	06 December 2019
Brendan	11 January 2020
Ciara	05 February 2020
Dennis	11 February 2020
Jorge	27 February 2020

All these factors highlight the challenges facing a project carried out during the winter months.

As the second set of aerial flights were not able to be undertaken, additional shore surveys were programmed in order to revisit the control holes.

2.4 Field survey methodology

An experienced marine biologist accompanied the drone pilot to each site to dig control holes, identify the habitats and biotopes present and to help ground truth and calibrate the bait digging evidence that could be identified from the UAV.

2.4.1 Control holes

Two control holes (approx. 0.5 m x 0.5 m by 0.3 m deep) were dug at stations on each site where evidence of bait digging (either current or historic) was identified. These holes were intended to replicate bait digging holes. These were marked with a sheet of A4 paper to help identify them on the aerial imagery. A GPS fix was taken on the holes, for relocation on subsequent visits.

One pair of control holes were dug where the site was relatively small and the areas bait dug appeared uniform. On more extended sites, multiple stations were used and hence several pairs of control holes were dug (such as Beaumaris – Penmon where 4 pairs were dug).

These control holes provided reference scales for interpreting the aerial imagery. These helped to identify the appearance of a freshly dug hole when digitising bait digging areas from the aerial photographs. By revisiting these, they also allowed information to be gathered on the speed at which bait digging evidence disappeared at the different sites to provide further evidence site recovery.

Figure 3 - Station 3 at Lleiniog Beach showing control hole marked with A4 paper. Note highly pitted surrounding sediment

It was initially intended to choose a 10 m x 10 m area with corners on the 2 control holes and then to count and score the age of all pits in the area. In practice, there were very few distinct pits that could be counted on any of the sites. Many areas were completely dug with individual holes indistinguishable. Therefore, this method of attempting to assign numbers and typical age of holes in a representative area was not used throughout the rest of the survey.

If significant bait digging was observed this was recorded.

2.4.2 Shore survey

For each site, the following information was collected:

- Habitat description / substrate type, giving the biotopes present on the shore (focussed primarily on the areas being dug).
- Type(s) of digging practice noted (e.g. trenches, holes, pumping)
- Typical freshness / age of holes at the site and any other notable characteristics of the digging.
- Confirmation of the target species (if evident). Common names are used when species identification was not made (e.g. name relayed by bait diggers or inferred). Scientific names are used when species was identified.
- Approximate percentage of holes backfilled (if this is evident from site visits).
- Holes / impacts made from activities other than bait digging.

Shore exposure was recorded using the exposure scales developed during Marine Nature Conservation Review (MNCR). Hiscock, K (1996) is a modified Ballentine scale but with the addition of an Ultra sheltered category and was used in this study.

Details of the weather conditions, which may influence the quality of the survey, time and tidal state on each survey were noted.

Additional still photographs were taken of the visual signs of bait digging that were encountered at the site as further evidence. These illustrated the observations listed above, as an index of types of digging. Photographic evidence was collected from as many locations at the sites as possible to help illustrate the nature of the digging at the site.

Additional information collected:

- If bait diggers were present during the site visit, then the number and their activities were noted in as much detail as possible.
- Obvious / characterising species needed to establish a biotope for each station
-

The data from each field visit was written up as a field log. These are referenced in this report.

2.5 Aerial image processing

The aerial images captured in the field were subsequently processed using Pix4D Mapper www.pix4d.com/product/pix4dmapper-photogrammetry-software. Using the

Real Time Kinematic (RTK) facility of the eBee UAV, it is possible to achieve cm level accuracy and orthomosaiced outputs. The outputs include a Digital Surface Model (DSM).

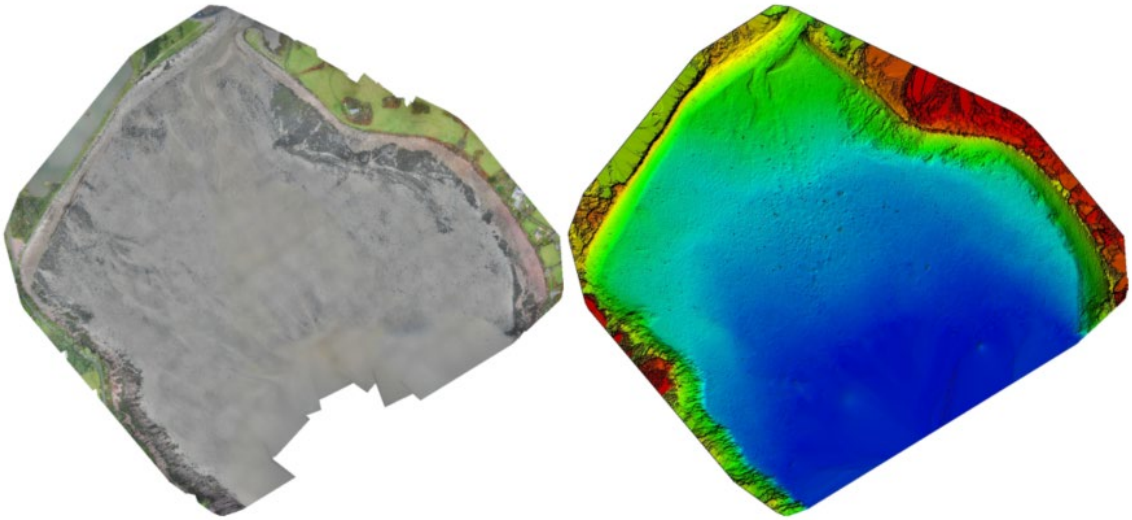


Figure 4 - Example of Orthomosaic (left) and the corresponding Digital Surface Model (DSM) (right) for Gann Flats.

The outputs from Pix4D also give details on the quality of the calculated image. Figure 5 shows an example from the Gann Flats showing number of overlapping images computed for each pixel of the orthomosaic. Ideally each pixel should be covered by at least 5 images.

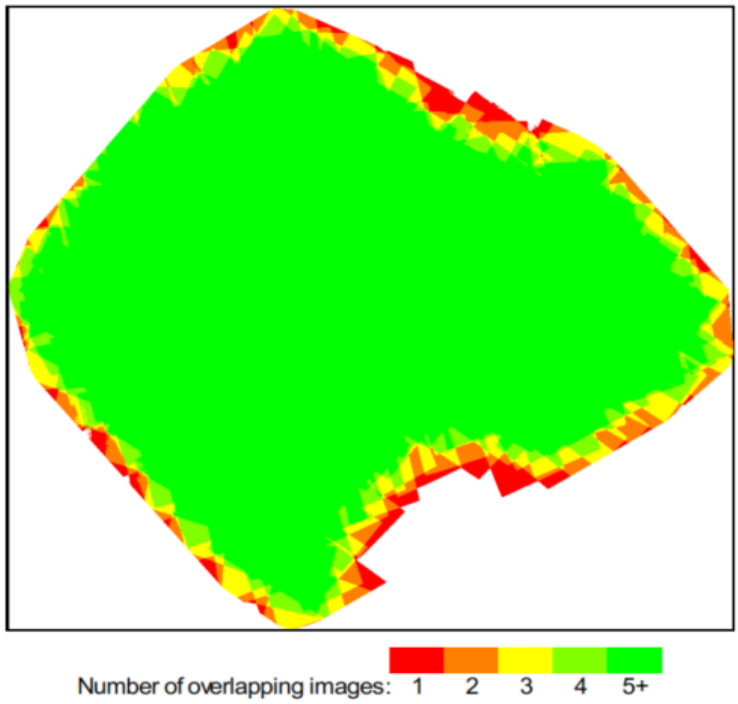


Figure 5 - Example from the Gann Flats showing number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel.

A completely uniform image with no identifying features can make it impossible to match overlapping images. The processing software identifies keypoints on images that can be matched. Figure 6 shows a typical example for the Gann Flats where 6549670 2D keypoint observations were located.

Figure 6 shows that more keypoint features identified around the edge of the beach and that there is an area in the middle of the beach (which is largely flat sediment) where fewer keypoints were located. Although not an ideal situation, enough keypoints were still identified in order to process the image.

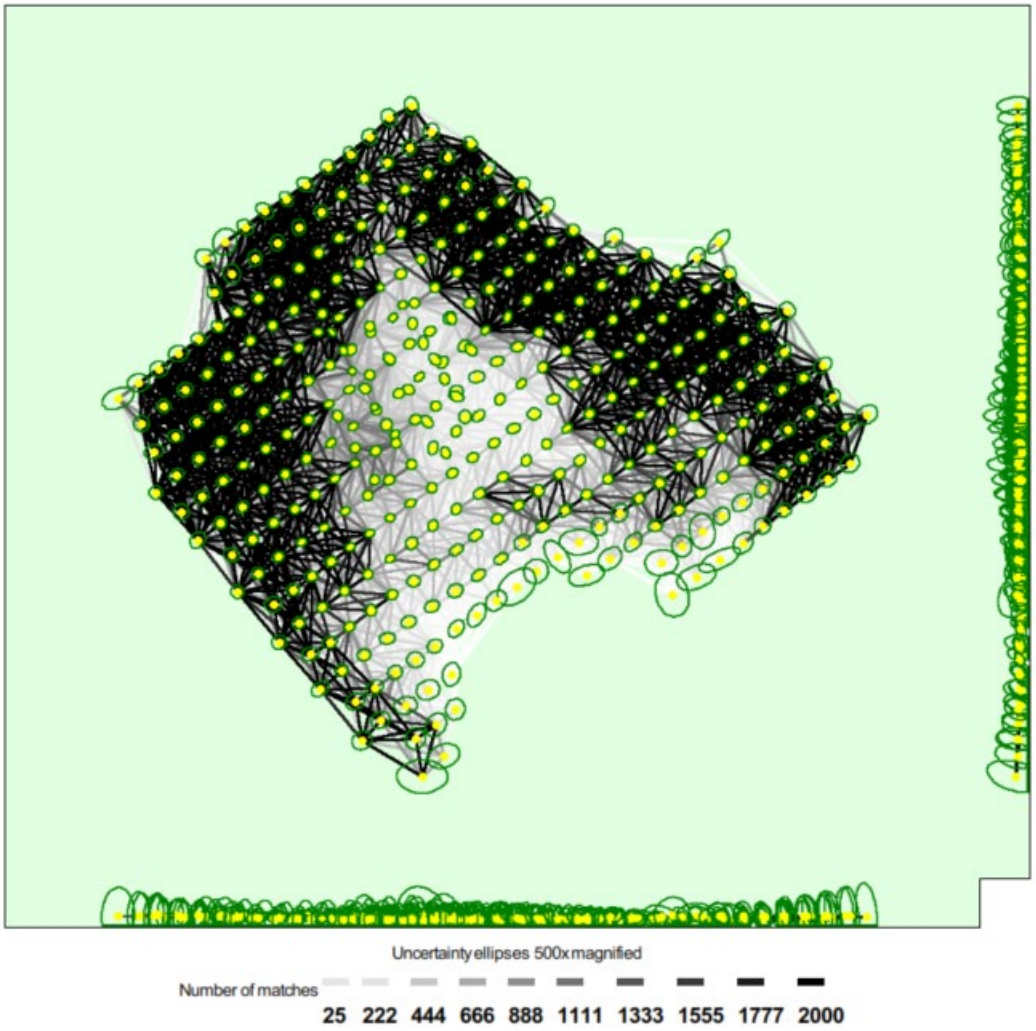


Figure 6 - Example from the Gann Flats showing computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images.

The full Pix4DMapper reports for each of the flights are included with the aerial imagery.

2.5.1 Spatial data capture

A virtual raster was created for each site using the aerial imagery tiles, as this provides increased performance over full site images. To further increase performance, the virtual rasters were set to display only below 1:2,000 scale.

Ground truthing involved the surveyor and the digitiser discussing how to map and attribute polygons in the area that was visited on foot. The digitiser established what could be identified on the aerial photograph and then the field surveyor advised whether areas seen were bait digging and if so what intensity and confidence should be attached to this. This allowed a “calibration” for each site which then, on the larger sites in particular, could be extrapolated to areas that were not visited on foot.

In some situations, the evidence of bait digging was obvious and clearly identifiable on the ground (Figure 7). In some areas, the evidence was less distinct and confidence would have been lower from aerial imagery (Figure 8).

A 100 m grid was applied over each site, to help ensure all areas were examined. Aerial imagery was inspected and any evidence of bait digging captured at 1:250 scale. Beyond this it was found that fainter evidence of bait digging could not be reliably identified. This applied to all sediment types.

The map scale applied during data capture meant that areas mapped were smaller than anticipated. Discrete new holes amongst evidenced older holes were often mapped as small polygons just containing the hole and spoil heap. Other areas that could have been mapped contiguously were captured separately, as this was easier at the mapping scale used.

A scale of 1:500 was used to review areas where evidence of bait digging was not expected to be seen, such as areas covered by deep water and rocky areas. Squares in the 100 m grid were checked off as they were reviewed. All aerial imagery available for each site was reviewed. This meant that occasionally some evidence of bait digging was captured outside of the original site boundaries.

Conventional heat mapping techniques could not be used to show intensity of bait digging. Few individual bait digging holes could be identified within polygons, thus maps based on the number of holes could not be generated. Instead general areas were mapped and given a bait digging intensity attribute.

Figure 7 - Example of high intensity bait digging at Beddmanarch (centre of image) with likely older evidence to right of image.

Figure 8 - Less distinct bait digging at Llanfair yn Neubwll

2.5.2 Attributes captured

Polygons were used to map apparent evidence of bait digging. Each polygon was attributed as follows:

- **Intensity of bait digging**. The approximate percentage of the mapped area covered by visible evidence of bait digging was recorded using the following bands:
    - ‘High’ = greater than 80%
    - ‘Medium’ = between 30% and 80%
    - ‘Low’ = less than 30%.
- In practice, high intensity was for those areas that were more or less continuously covered with evidence. Note that evidence in this instance includes spoil, so for every hole there is usually an equivalent area of disturbed sediment/spoil that is also mapped. The remaining 20% can be untouched. The cut off between high and medium was usually relatively distinct, as an area was often either thoroughly dug or occasionally dug.

- The intensity thresholds were determined on a pragmatic basis based on a review of the aerial photographs examined and how the visual evidence of bait digging could be most practically categorised.

Intensity was not always easy to determine where frequent human trampling obscured evidence of bait digging, or where footprints merged to form larger depressions that resembled bait digging holes. Though these bands may not always be an accurate measure of the intensity of bait digging, they will be a good measure of the intensity of disturbance. Additionally, this level of activity generally only occurred where bait digging took place, so it is unlikely that areas have been incorrectly included in the mapped areas due to high levels of human disturbance.

- **Age of the evidence.** Evidence of bait digging where there was clearly defined evidence of holes or recent spoil was recorded as ‘New’ (the control holes provided a guide for this). Other evidence, including where holes and spoil was clearly starting to flatten out as a result of tidal action, was recorded as ‘Old’.
- **Confidence in interpretation.** Based on the clarity of evidence on the aerial photography and supported by ground truthing, confidence was recorded as follows:
    - ‘High’ = completely confident that the visible evidence related to bait digging activity. This was more likely to be selected where the age of the evidence was recorded as ‘New’.
    - ‘Medium’ = moderately confident that the visible evidence related to bait digging activity.
    - ‘Low’ = poor confidence that the visible evidence related to bait digging activity.
    - ‘Very low’ = applied where there was only the faintest evidence of bait digging activity or where disturbance was visible without clear evidence

of bait digging holes. The intention was to map areas that probably were affected by bait digging but for which insufficient evidence was visible in aerial images or ground truthing. This category was added part way through the contract during the capture of Gann Flats, due to the extreme uncertainty of some areas on that site, and was only applied to Gann Flats, Beddmanarch Bay, Y Foryd Bay and Llanfair un Neubwll.

- Medium, low and very low confidence evidence often graded into each other, without clear boundaries between them. In such cases they were divided with a line approximately through the middle of the gradation.

2.5.3 Digital Surface Modelling processing

Digital Surface Models (DSMs) were created for all sites from the aerial imagery (Figure 4). Two approaches were used to determine whether these DSMs could be useful for identifying evidence of bait digging:

- Shaded Relief Modelling (SRM)
- Local Relief Modelling (LRM).

Both are frequently applied to identify faint evidence of archaeological remains in the ground that may not otherwise be visible.

SRM is an approach that applies a modelled light source to the DSM and shows the shadows cast. The altitude of the light source above the horizon, and significantly its azimuth (the angular distance from north), can be set, allowing lighting that could not naturally occur. Issues occur where steep slopes or edges face away from the light source, as they can cast shadows that obscure otherwise visible features. It is also possible for a feature to be obscured if its orientation in relation to the light source prevents it from casting a shadow, for example a trench on a hilltop that points towards the light source. Because the values of the resultant raster correspond only to the strength of the shadow, they are meaningless in their own right.

LRM is an approach that removes large-scale topological variation in a Digital Surface Model DSM leaving only small-scale variation. Simply described, it subtracts a generalised version of the DSM from the original to produce a broadly flat DSM with only small variations remaining. This means that the small-scale variation can be visualised in a way that would be obscured on the original DSM due to greater variations in altitude. Unlike shaded relief models, LRMs are not affected by shadows cast on steep slopes or the orientation of the feature. It is also possible to interrogate LRMs to determine the difference between the altitude of a visible feature and that of the generalised (averaged) model.

SRMs and LRMs were created for subjectively selected DSM tiles where evidence of bait digging could be seen and where it couldn't. SRM were applied directly to the DSM in the QGIS symbology settings. LRMs were created in GRASS GIS using the *r.local.relief* command.

3. Results

The study has established the usefulness of drones for surveying the location and intensity of bait digging at a point in time and the contract has also provided a snapshot of the location of bait digging at these selected priority sites in Winter 2019/2020. Whilst these pilot methods may not represent complete coverage, in many cases the outputs represent the first mapped evidence of bait digging at these locations.

Due to the study occurring over winter, it is likely that less bait digging was taking place on many of the sites, although evidence from some shores in south Wales indicates that digging continues at high levels during the winter and spring. On the Gann Flats, for example Evans et al (2015) state:

"The flats are subject to year round baitworm exploitation with digging intensity varying spatially across the site throughout the year. Peak digging intensity occurs during the Autumn-Winter period but Morrell (2007) found that significant activity occurs outside of peak periods with up to 306 holes per 2500m^{-2} identified in the central part of the mudflat during a survey of bait holes on the flat in spring."

The results show what can be determined from drone flights with ground truthing. The length of time that evidence of bait digging remains visible will differ from shore to shore depending upon substrate and exposure, as evidenced in this report.

Whilst many sites are considered sheltered or very sheltered, the exceptional level of storminess during winter 2019 / 2020 (**Table 2**), will likely have resulted in wave action on these sites greater than might be expected under normal conditions. This has resulted in unusual smoothing of otherwise sheltered habitats and also the possibility of sedimentation of fine sediments (post-storm), which were lifted from adjacent sediment flats during the storms.

The maps displaying bait digging at each site can only give an overall impression of bait digging activity at each location. Some of the areas mapped (especially relating to new bait digging) are very small and the GIS data needs to be examined if details of all areas dug are to be observed.

Visit timeline

Sites were visited at a range of dates over the autumn, winter and early spring 2019/20, as tides and weather allowed. The table below gives an overview of site visits.

Table 3 - Timeline of site visits

Location	September 2019	October 2019	November 2019	December 2019	March 2020
Beaumaris, Menai Strait (Station 1)	30/9 – Dig test holes Aerial survey	1/10 – Aerial survey Test holes visible	N/A	10/12 – attempt ground survey. Storm surge. Test holes inaccessible	10/3 – Ground survey. Test holes faintly apparent with coarser material where the spoil heap was. Fucoid cobble in one of shallow remains of the test hole. Whole shore sediment much smoother than initial observations. 162 Days since digging test holes.
Beaumaris (Station 2), Saunders & Roe sheds, Menai Strait	30/9 – Dig test holes Aerial survey	1/10 – Aerial survey Test holes visible	N/A	10/12 – attempt ground survey. Storm surge. Test holes inaccessible	10/3 – Ground survey. No obvious trace of the test holes. Much smoother than initial observations. 162 Days since digging test holes.
Beaumaris (Station 3), Lleiniog Beach, Menai Strait	30/9 – Dig test holes Aerial survey	1/10 – Aerial survey Test holes visible	N/A	10/12 – attempt ground survey. Storm surge. Test holes inaccessible	10/3 – Ground survey. Test holes apparently blended with other existing depressions. Whole shore smoother than initial observations. 162 Days since digging test holes.

Location	September 2019	October 2019	November 2019	December 2019	March 2020
Beaumaris (Station 4), Trwyn y Penrhyn / Porth Penmon, Menai Strait	30/9 – Dig test holes Aerial survey	1/10 – Aerial survey Test holes visible	N/A	10/12 – attempt ground survey. Storm surge. Test holes inaccessible	10/3 – Ground survey. Test holes still apparent in soft muddy sediment. Rest of shore area much smoother than initial observations. 162 Days since digging test holes.
Y Foryd, Menai Strait	N/A	27/10 – Dig test holes Aerial survey	N/A	N/A	10/3 – Ground survey. Test holes no longer apparent. Sediment surface rippled sand. 132 days since digging test holes.
Penrhos Beach, Holyhead	N/A	2/10 – Dig test holes in mobile rippled sand. Aerial survey	N/A	N/A	Area not resurveyed – mobile sediment not considered high priority.
Gorad Rd, Beddmanarch Bay	N/A	28/10 – Dig test holes Aerial survey (part)	10/11 - Aerial re-flown in 2 areas. Test holes apparent	21/12 – Ground survey. Test holes covered by tide	4/3 – Ground survey. Test holes apparent, now with fucoid cobbles in 1 hole. 128 days since digging test holes
Cob, Beddmanarch Bay	N/A	28/10 – Dig test holes Aerial survey (part)	10/11 - Aerial re-flown in 2 areas. Test holes apparent	21/12 – Ground survey. Test holes clearly apparent.	4/3 – Ground survey. Test holes clearly apparent. Fucoid cobbles in holes. 128 days since digging test holes

Location	September 2019	October 2019	November 2019	December 2019	March 2020
				Fucoid cobbles in holes.	
Llanfair yn Neubwll, Cymyran Strait	N/A	N/A	10/11 - Dig test holes Aerial survey	21/12 – Ground survey. Test holes clearly apparent.	3/3 – Ground survey. Test holes clearly apparent. 115 days since digging test holes.
Four Mile Bridge, Cymyran Strait	N/A	N/A	10/11 - Dig test holes Aerial survey	N/A	4/3 – Ground survey. Area heavily dug; test holes possibly apparent. 115 days since digging test holes.
Inland Sea, Cymyran Strait	N/A	N/A	N/A	21/12 – Attempt ground survey. Tide too high.	3/3 – Ground survey. First time tide sufficiently low. Few signs of bait digging. *Zostera noltei* and filamentous algae binding sediment habitats.
Gann Flats, Milford Haven	N/A	N/A	28/11 - Dig test holes Aerial survey	N/A	14/03 – Visual evidence of previous holes is not immediately obvious.
Sandy Haven Pill, Milford Haven	N/A	N/A	28/11 - Dig test holes Aerial survey	N/A	14/03 – holes were still clearly visible and had been slightly enlarged by scour over this time.

Location	September 2019	October 2019	November 2019	December 2019	March 2020
Gelliswick Bay, Milford Haven	N/A	N/A	29/11 - Dig test holes Aerial survey	N/A	14/03 – holes had largely filled in, although the location of one of one holes could be identified by a ring of gravelly substrata in the holes previous location
Angle Bay, Milford Haven	N/A	N/A	29/11 - Dig test holes Aerial survey	N/A	15/03 – holes were no longer visible but still represented by soft liquid sediment
Swansea Bay	N/A	N/A	N/A	N/A	13/03 - Aerial survey

3.1 Between Beaumaris and Penmon

Figure 9 - Survey area – Between Beaumaris and Penmon

Table 4 - Beaumaris to Penmon visit summary

Category	Information about site surveyed
Date(s) of flight	30/09/2019 - 01/10/2019
Time of flight	06:50 – 08:30
Local LW time	06:48 (Beaumaris) (30/09/2019) 07:20 (Beaumaris) (01/10/2019)
Field report	20191003 field report bait digging Beaumaris and Penrhos Bay.docx
Tiled image file	Beaumaris_North_20191001.tif Beaumaris_South_20191001.tif
Control stations and habitat(s) observed	**Station 1** - SH 61049 76917 - Mid and lower shore fine muddy sand. No new dug holes but many contiguous water-filled depressions. *LS.LSa.MuSa - Polychaete/bivalve-dominated muddy sand shores*. **Station 2** - SH 61365 77470 - Mid and lower shore muddy sand. Lots of contiguous holes and depressions. No newly dug holes. LS.LSa.MuSa - Polychaete/bivalve-dominated muddy sand shores **Station 3** - SH 62343 79110 - Fine sandy mud with scattered large boulders. Soft silty surface layer overlying muddy sand with deeper gravelly layer. *Hediste, Corophium, Arenicola* and possibly *Scrobicularia*. This possibly corresponds to the JNCC level 5 biotope LS.LMu.MEst.HedMacScr Hediste diversicolor, Macoma balthica and Scrobicularia plana in littoral sandy mud or the level 4 biotope LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores. **Station 4** - SH 63119 79986 - Soft sandy mud with anoxic sub-layer. Large boulders nearby with *Fucus serratus*.

Category	Information about site surveyed
Date(s) of flight	30/09/2019 - 01/10/2019
	LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores
Shore exposure	Sheltered
Area of site	176 ha
Bait diggers observed	1 bait digger observed near Picnic Site at Lleiniog. Hole digging – no backfilling
Target species	Ragworm and King ragworm at all stations, additionally Lugworm at station 2
Date of follow up visit	10/03/2020 (162 days)

Figure 10 - Station locations at Beaumaris to Penmon

Mapping Beaumaris to Penmon

Table 5 - Area in m² of bait digging evidence mapped on Beaumaris to Penmon, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	No data	65
Medium	12,887	No data
Low	1,179	No data
Total	14,066	65

Medium intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	139,739	No data
Low	24,056	No data
Total	163,795	0

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	19,989	No data
Low	3,636	No data
Total	23,625	0

Total dug old and new

Old (age)	New (age)	Combined
201,486	65	201,551

A total of 65 m² of new and c.20 ha of old evidence of bait digging was mapped at Beaumaris. Overall this covered about a tenth of the site.

Most of the evidence of bait digging at Beaumaris was distinct. Issues occurred where seaweed covered boulders were present in holes, which gave reduced confidence that bait digging rather than natural scour was the cause. There was also evidence of non-natural disturbance in the south near Beaumaris Green (c. 2,300 m²), but this may not have been caused by bait digging. There is a possibility that these could be marks from previous gravel extraction or beach feeding using mechanical diggers.

Some of the imagery for Beaumaris was not of sufficient quality (due to low light levels) to accurately identify evidence of bait digging in these areas (Figure 9). This issue mainly affected the southern half of the site.

Bait digging between Beaumaris and Penmon was concentrated in three main areas:

East of Penmon. This covered 12 ha but included no recent or high confidence evidence of bait digging other than two test holes.

East of Lleiniog Beach Picnic Site, Llangoed. This covered 2.4 ha but was high intensity. Some isolated new bait digging occurred east of the main area, perhaps because this area is less frequently exposed or evidence of bait digging survives less well in this area.

East of the junction of the B5109 and Ffordd Eglwys, Llanfaes. This covered 4.6 ha of mainly moderate intensity evidence of bait digging, although no new evidence was present other than the two test holes.

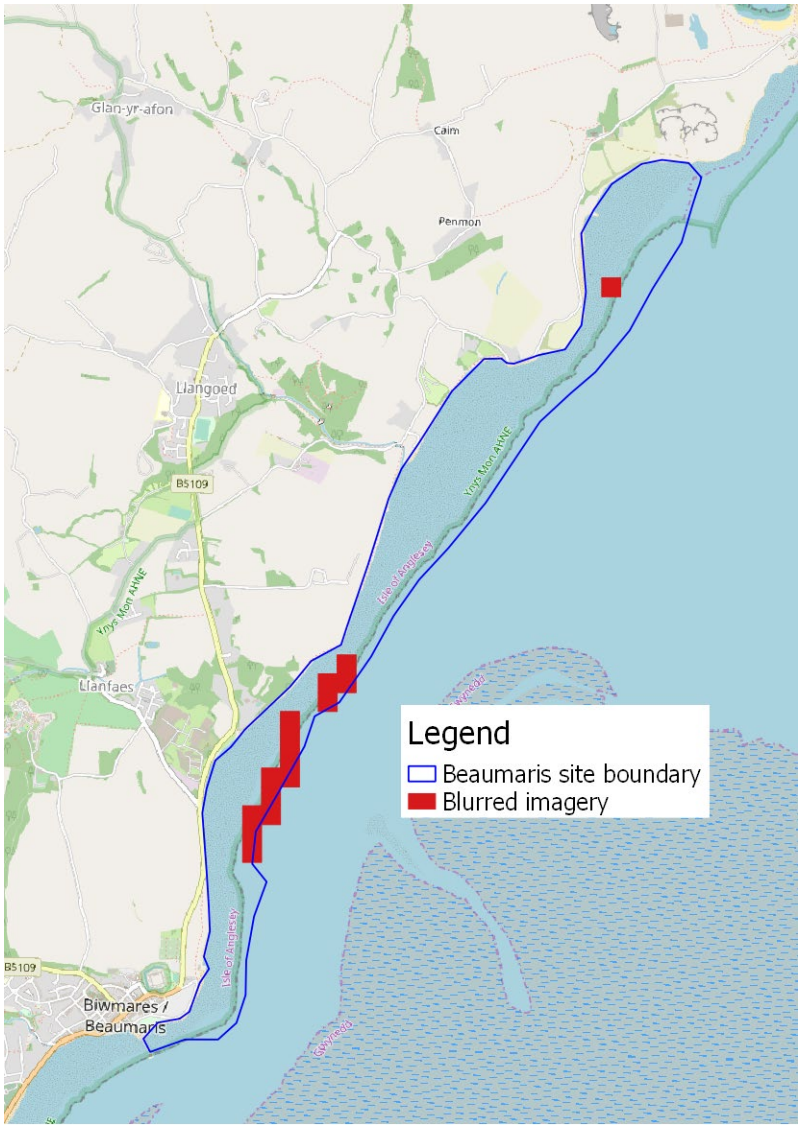


Figure 11 - Areas of poor imagery between Beaumaris and Penmon

Figure 12 - Bait digging Beaumaris - Penmon (North). Heavy black borders of polygons indicate newly dug areas.

Figure 13 - Bait digging – Beaumaris – Penmon (Centre). Heavy black borders of polygons indicate newly dug areas.

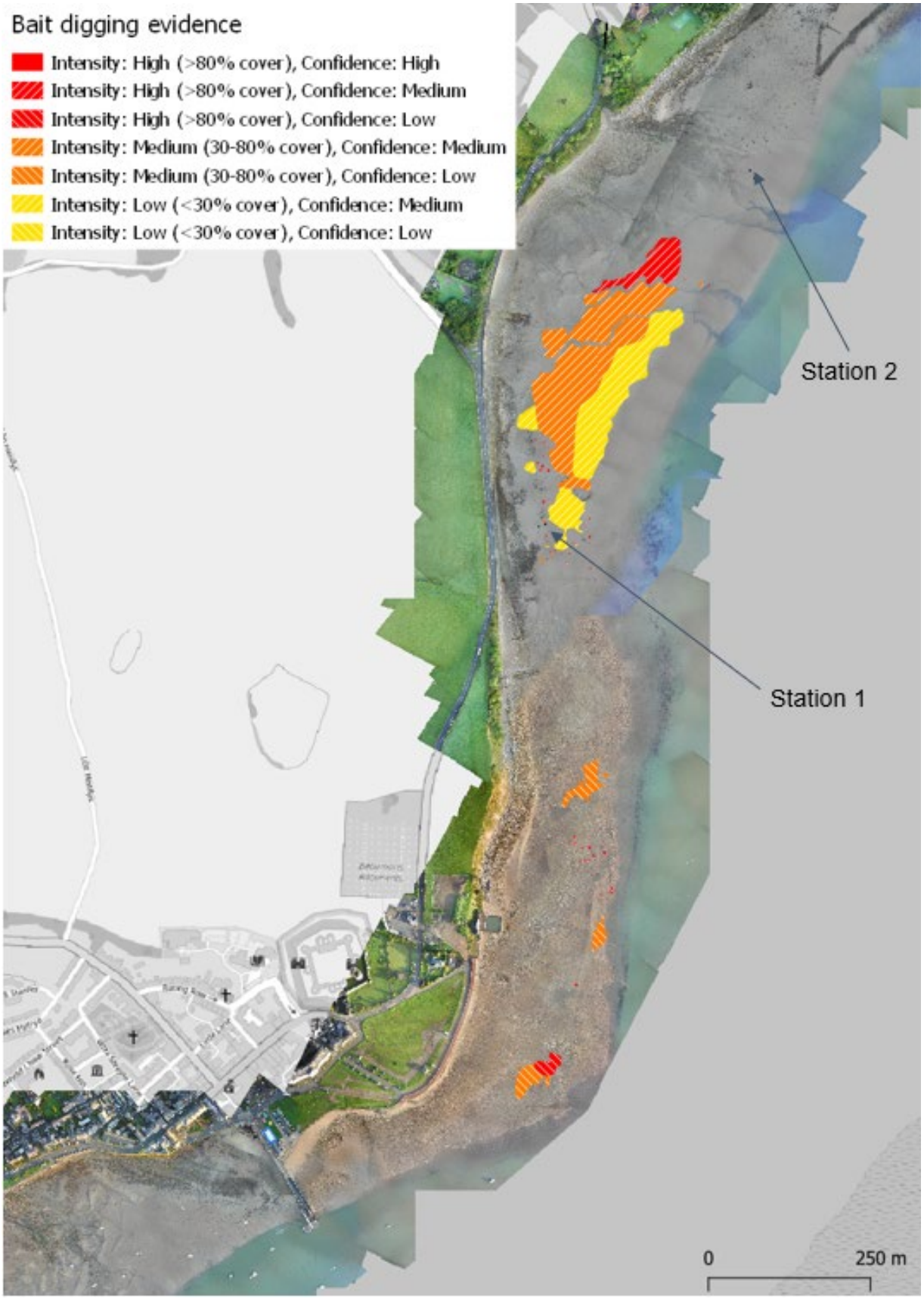


Figure 14 - Bait digging – Beaumaris - Penmon (South). Heavy black borders of polygons indicate newly dug areas.

Shore survey - Beaumaris (Station 1), Menai Strait.

General description and accessibility

The shore surveyed was immediately adjacent to the main B5109 Beaumaris to Penmon road, just north-east of Beaumaris, with parking and easy access nearby. The shore was backed by a wall followed by a short cobble slope leading on to an extensive area of gently sloping muddy sand grading into sandy mud with scattered fucoid-covered boulders and cobbles on the upper-mid part of the beach, Figure 15. The shore is very sheltered from wave action (<20 km fetch and <3 km fetch from prevailing winds), and although adjacent to the moderately strong flow of the Menai Strait, the shore itself only experiences weak (<1 kn) tidal flow.

Figure 15 - General wide-angle view of the shore showing the range of habitats present. Arrow shows approximate location of the control holes.

Bait digging distribution

On the first visit to this site at the end of September 2019 there was no sign of recent or freshly dug holes, but the entire surface of the mid and lower sediment portion of the shore was marked with shallow, contiguous depressions at an approximate abundance of >1 per m^2. The depressions ranged in size from </= 30 cm (possibly the remains of footprints) to around 1 m across (possible bait digging holes) and all were around 1 – 5 cm deep and water-filled.

Figure 16 - Control hole dug at dawn 30/09/2019 with recently made footprints. The sediment surface is covered with many shallow pits and depressions

Habitat

The sediment at the location of the control holes was dark-coloured, soft, muddy fine sand with the RPD layer almost immediately below the sediment surface. Fauna observed while digging included *Cerastoderma edule* and polychaetes but the infauna was not sampled in detail. This corresponds to the JNCC level 4 biotope *LS.LSa.MuSa -Polychaete/bivalve-dominated muddy sand shores*.

Spatial variability observed

The shore approximately one hundred metres to the NE and SW graded into less muddy coarser sediment and gravel with fucoid-covered cobbles and boulders and the remains of old slipways. The area of apparently disturbed-looking sediment was confined to the muddier section of shore where the control holes were dug.

Persistence of bait digging

The stable nature of the muddy sediments in this area probably retains evidence of topographical disturbance for weeks or months, although it would seem likely that deep holes and tall spoil heaps of soft sediment will be partially smoothed after a few tidal cycles. The initial observations were made and control holes were dug at the end of September 2019 and the last observations made 162 days later in March 2020. During that period, the whole area of sediment shore adjacent to where the control holes were dug lost its appearance of having been heavily worked or disturbed. There were a few shallow depressions remaining in March 2020 (estimate 0.25 per m^2 and approximately 1 cm deep) but these were not as frequent or pronounced as those seen in autumn 2019. There were traces of the original control holes, which remained as very shallow depressions, and small areas of coarse gravel

and shell marked the spoil heaps. One of the holes contained a fucoid-covered cobble.

It is likely that winter storms have smoothed the whole-shore sediment topography that accumulated signs of pitting and damage over the calmer summer months. It is also possible that a layer of silt and sand has been deposited on the shore which has also in-filled the pitted topography.

Figure 17 – Close-up view of one of the control holes 30/09/2019.

Figure 18 - The remains of the above control hole in Figure 17 (red ellipse) and spoil heap (yellow ellipse) on 10/03/2020 (162 days since digging). The rest of the sediment surface at this site was notably smoother than seen during the first visit.

Issues encountered

Low water of spring tides in the Menai Strait typically occurs in the early morning or late afternoon / evening. At the time of initial sampling and aerial survey, low light levels limited the opportunities for drone flights which can only take place in calm conditions with no rain. The control holes were dug pre-dawn and low light levels limited the quality of both aerial and ground level photography.

Shore survey - Beaumaris (Station 2), Saunders and Roe Sheds, Menai Strait

General description and accessibility

The shore surveyed was a short walk from the main Beaumaris to Penmon road (B5109) with parking in the layby next to the Saunders and Roe sheds and easy access to the shore via a footpath across the road. The shore was backed by a line of trees leading down to a cobble and shingle slope sparsely covered in barnacles and fucoids on the upper-mid part of the shore. An area of very wet, muddy sand extended beyond the cobbles to the water line bounded by the remains of old slipways to the SW and cobble and gravel shore to the NE. The shore is very sheltered from wave action (<20 km fetch and <3 km fetch from prevailing winds), and although adjacent to the moderately strong flow of the Menai Strait, the shore itself only experiences weak (<1 kn) tidal flow.

Figure 19 - The two control holes dug in the very pitted surface on muddy sand and gravel near to the Saunders and Roe sheds.

Bait digging distribution

At the end of September 2019 there was no sign of recent or freshly dug holes, but the entire surface of the mid and lower sediment portion of the shore was marked with a dense cover of shallow, contiguous depressions at an approximate abundance of >4 per m^2. The depressions ranged in size from </= 30 cm (possibly the remains of footprints) to around 1 m across (possible bait digging holes) and all were around 1 – 5 cm deep and water-filled. When re-surveyed in March 2020 the whole shore had lost its pitted nature.

Figure 20 - The control holes on 30/09/2019 (left) and the same area 10/03/2020 (right) 162 days later. The sediment surface has lost its pitted appearance and there are no signs of the control holes

Habitat

The sediment at the location of the control holes was sandy-coloured, cohesive, muddy fine sand with the RPD layer almost immediately below the sediment surface. Fauna observed while digging included *Cerastoderma edule* and polychaetes but the infauna was not sampled in detail. This corresponds to the JNCC level 4 biotope *LS.LSa.MuSa - Polychaete/bivalve-dominated muddy sand shores*.

Spatial variability observed

The muddy sand area of shore was approximately one hundred metres wide and bounded by an old slipway to the SW and graded into less muddy coarser sediment with a veneer of pebbles and gravel to the NE. The area of apparently disturbed-looking sediment was confined to the muddy sand section of shore where the control holes were dug.

Persistence of bait digging

The stable nature of the muddy sandy sediments in this area probably retain evidence of topographical disturbance for weeks or months, although it would seem likely that deep holes and tall spoil heaps of soft sediment will be partially smoothed after a few tidal cycles. The initial observations were made and control holes were dug at the end of September 2019 and the last observations made 162 days later in

March 2020. During that period the whole area of sediment shore adjacent to where the control holes were dug lost its appearance of having been heavily worked. There was no sign of the control holes or spoil heaps and thinly scattered pebbles and coarse gravel overlying muddy sand now cover most of the area that was previously pitted muddy sand. It is possible that the winter storms have levelled the pitted nature of the sediment that accumulated damage during the calmer summer months and have also moved a thin layer of coarser material over the area.

Issues encountered

As with the other sites in the Menai Strait sampled during the autumn and winter, low water of spring tides corresponded to poorly lit times of day which limited the quality of aerial and ground-based images.

Shore survey - Beaumaris (Station 3), Lleiniog Beach, Menai Strait

General description and accessibility

The shore surveyed was a short walk from the Lleiniog Beach picnic site which has off-road parking with easy access to the shore. The shore was backed by a car park and low-density woodland leading down concrete steps to a boulder and cobble slope on the upper-mid part of the shore. An area of wet, muddy sand with scattered large fucoid-covered boulders extended beyond the cobbles to the water line, bounded by the remains of old walls (fish traps) to the SW and NE. The shore is very sheltered from wave action (<20 km fetch and <3 km fetch from prevailing winds), and although adjacent to the moderately strong flow of the Menai Strait, the shore itself only experiences weak (<1 kn) tidal flow. Small freshwater creeks followed the lines of boulders down the shore.

Figure 21 - Approaching the station from the upper shore at Lleiniog beach. The arrow indicates the approximate position of the control holes adjacent to the line of boulders down the shore.

Bait digging distribution

In September 2019 there was no sign of recent or freshly dug holes, but the entire surface of the mid and lower sediment portion of the shore was marked with a dense cover of shallow (but slightly deeper than the previous two stations), contiguous depressions at an approximate abundance of >4 per m^2. The depressions ranged in size from </= 30 cm (possibly the remains of footprints) to around 1 m across (possible bait digging holes) and all were around 1 – 10 cm deep and water-filled. There was no bait digging activity at the time the control holes were dug, but several people were seen bait digging here the day after.

Figure 22 - The two test holes in very pitted and scarred fine muddy sand.

Habitat

The sediment at the location of the test holes was sandy-coloured, cohesive, muddy fine sand with the RPD layer almost immediately below the sediment surface. Fauna observed while digging included *Hediste* sp. *Arenicola marina*, *Corophium volutator* and *Scrobicularia plana* but the infauna was not sampled in detail. This possibly corresponds to the JNCC level 5 biotope *LS.LMu.MEst.HedMacScr Hediste diversicolor, Macoma balthica and Scrobicularia plana in littoral sandy mud* or the level 4 biotope *LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores*.

Spatial variability observed

The muddy sand area of shore was several hundred metres wide and intersected by lines of boulders running down the shore to the SW and NE with freshwater creeks following them. The area of apparently disturbed looking sediment was mainly on the mid-section of the shore but extended well beyond the area adjacent to the control holes.

Persistence of bait digging

The stable nature of the muddy sandy sediments in this area probably retain evidence of topographical disturbance for weeks or months, although it would seem likely that deep holes and tall spoil heaps of soft sediment will be partially smoothed after a few tidal cycles. The initial observations were made and control holes were dug at the end of September 2019 and the last observations made 162 days later in March 2020. During that time the general appearance of the whole area of shore adjacent to the test holes changed. Although still pitted with the apparent remains of many contiguous holes (now fewer at approximately 2 per m^2), the sediment surface and the three-dimensional topography was far smoother. The original control holes

could not be positively identified, but there were many shallow pits and mounds at the recorded position. It is possible that the winter storms have levelled the pitted nature of the sediment that accumulated damage during the calmer summer months, although this particular area in the Menai Strait appears more ‘worked’ and pitted than any of the others under investigation. The presence of the low walls and lines of boulder running perpendicular to the shore-line may stabilise the sediment and reduce wave action slightly and help preserve the sediment topography.

Figure 23 - The small hollow and the scattering of coarse material is possibly the remains of one of the control holes (red ellipse) and spoil heaps (yellow ellipse) 10/03/2020, 162 days later. Although still scarred, the sediment surface is smoother than during than during the first visit

Issues encountered

As with the other sites in the Menai Strait sampled during the autumn and winter, low water of spring tides corresponded to poorly-lit times of day which limited the quality of aerial and ground-based images.

Shore survey - Beaumaris (Station 4), Trwyn y Penrhyn / Porth Penmon, Menai Strait

General description and accessibility

The shore surveyed was accessed from where the road meets the shore at the NE side of Trwyn y Penrhyn. There is a parking area nearby. The shore was backed by a low wall followed by a cobble slope on the upper part of the shore which merged into fucoid covered boulders embedded in sandy sediment. This graded into an area of very wet, soft sandy mud (difficult to walk in) with a few scattered, very large fucoid-covered boulders down to the water line. The shore is very sheltered from wave action (<20 km fetch and <3 km fetch from prevailing winds) with extensive sand banks just offshore, and although adjacent to the moderately strong flow of the Menai Strait, the shore itself only experiences weak (<1 kn) tidal flow.

Figure 24 - The approximate area of Porth Penmon taken from Trwyn y Penrhyn where the control holes were dug.

Bait digging distribution

In September 2019 there was no sign of recent or freshly dug holes, but most of the surface of the mid and lower sediment portion of the shore was marked with a cover of shallow, contiguous depressions at an approximate abundance of >0.5-1 per m^2. The depressions ranged in size from </= 30 cm (possibly the remains of footprints) to around 1-2 m across (possible bait digging holes and long trenches) and all were around 1 – 10 cm deep and water-filled – some with fucoid-covered cobbles in the pools. There was no bait digging activity at the time the control holes were dug.

Figure 25. The view looking back up the shore at the highly scarred sediment surface 30/09/2019.

Habitat

The sediment at the location of the test holes was soft, dark, sandy mud with an anoxic black layer immediately below the surface. No fauna was observed during the digging process although large bivalve siphon holes were seen close by. The level 4 biotope *LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores* probably best fits the sediment habitat here.

Spatial variability observed

The sandy mud habitat, where the signs of bait digging were apparent, was restricted to the mid and lower shore at this site towards the middle part of the Porth Penrhyn embayment.

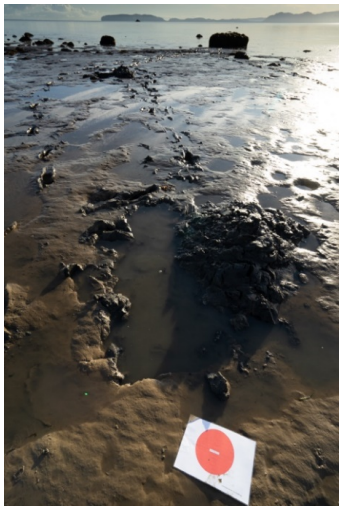


Figure 26 - Looking seawards at the control hole in soft mud.

Persistence of bait digging

The apparently stable nature of the muddy sediments in this area probably retain evidence of topographical disturbance for weeks or months, although the deep holes and tall spoil heaps of soft sediment from the control holes was partially smoothed after 24 hours. The initial observations were made and control holes were dug at the end of September 2019 and the last observations made 162 days later in March 2020. During that time the general appearance of the whole area of shore adjacent to the control holes changed markedly and lately appeared almost completely smooth. There were two large, shallow, water-filled depressions at the original recorded GPS positions that were likely to be the remains of the original test holes. The silty mud at this site was particularly soft, and in addition to being levelled by winter storm wave action, more silt has possibly been deposited on the shore further infilling the many depressions.

Figure 27 - The shallow remains of one of the control holes 10/3/2020 162 days after digging. The surrounding sediment surface is far smoother and has lost most of the scarring.

Issues encountered

As with the other stations in the Menai Strait sampled during the autumn and winter, low water of spring tides corresponded to poorly-lit times of day which limited the quality of aerial and ground-based images. The very soft mud at this station made walking to and from the site difficult and may deter bait diggers from using it as much as other easier to access sites further to the south east towards Beaumaris.

Comparison with other studies

Allen *et al.* (2008) include some shore mapping at Beaumaris and although now more than 10 years old the areas they identify with LMX.Psyllid habitat (a diverse muddy gravel biotope, now superseded by LS.LMx.Mx.CirCer) broadly agree with where the aerial imagery collected as part of this project has shown bait digging to

occur. The biggest discrepancy would be in the bay just south of Beaumaris lifeboat station. The area that Allen *et al.* 2008 identified is very low on the shore and in fact is partially covered by water on the aerial imagery suggesting bait diggers could rarely access it. Also, there are a lot of boat moorings showing on the aerial imagery collected. These may have increased in number, and / or scour marks from the moorings may make identification of bait digging harder.

3.2 Penrhos Beach

Figure 28 - Survey area - Penrhos Beach, Holyhead

Table 6 - Penrhos beach visit summary

Category	Information about site surveyed
Date(s) of flight	02/10/2019
Time of flight	0746-0800
Local LW time	0720 (Holyhead)
Field report	20191003 field report bait digging Beaumaris and Penrhos Bay.docx
Tiled image file	PenrhosBay_20191002.tif
Control stations and habitat(s) observed	**Station 1** - SH 26098 82083 Firm, rippled, mainly clean sand with sub-surface RPD layer. *Arenicola* casts occasional. Nearest rocky habitat c50m away with *Fucus serratus*. LS.LSa.MuSa Polychaete/bivalve-dominated muddy sand shores
Shore Exposure	Fairly sheltered
Area of Site	37 ha
Bait diggers observed	None – no backfilling observed
Target species	Arenicola marina (Lugworm)
Date of follow up visit	Not revisited

Mapping Penrhos Beach

A total of 7082 m² of old evidence of bait digging was mapped at Penrhos Beach (Table 7). Overall this covered less than a tenth of the site. All evidence of bait digging at Penrhos Beach was assessed as low confidence. There was no evidence of new bait digging at the site. The 'New' digging represents the trial holes dug and was therefore recorded as high confidence.

This suggests that there was not a high level of bait digging activity prior to the aerial survey, with only old activity just still visible. However, the aerial photography for Penrhos Beach was poor, being regarded as either blurry or very blurry. This is likely to have affected the ability to identify evidence of bait digging, especially where the evidence was less clear on the ground. The lower accuracy of the results for Penrhos Beach should be borne in mind.

Table 7 - Area in m² of bait digging evidence mapped on Penrhos Beach, broken down by age of evidence, intensity of evidence and confidence in the assessment. Note the New holes are the test holes dug.

High intensity

Confidence	**Old (age)**	**New (age)**
High	No data	7
Medium	No data	No data
Low	No data	No data
Total	0	7

Medium intensity

Confidence	**Old (age)**	**New (age)**
High	No data	No data
Medium	No data	No data
Low	7,082	No data
Total	7,082	0

Low intensity

Confidence	**Old (age)**	**New (age)**
High	No data	No data
Medium	No data	No data
Low	No data	No data
Total	0	0

Total dug old and new

Old (age)	**New (age)**	**Combined**
7,082	7	7,089

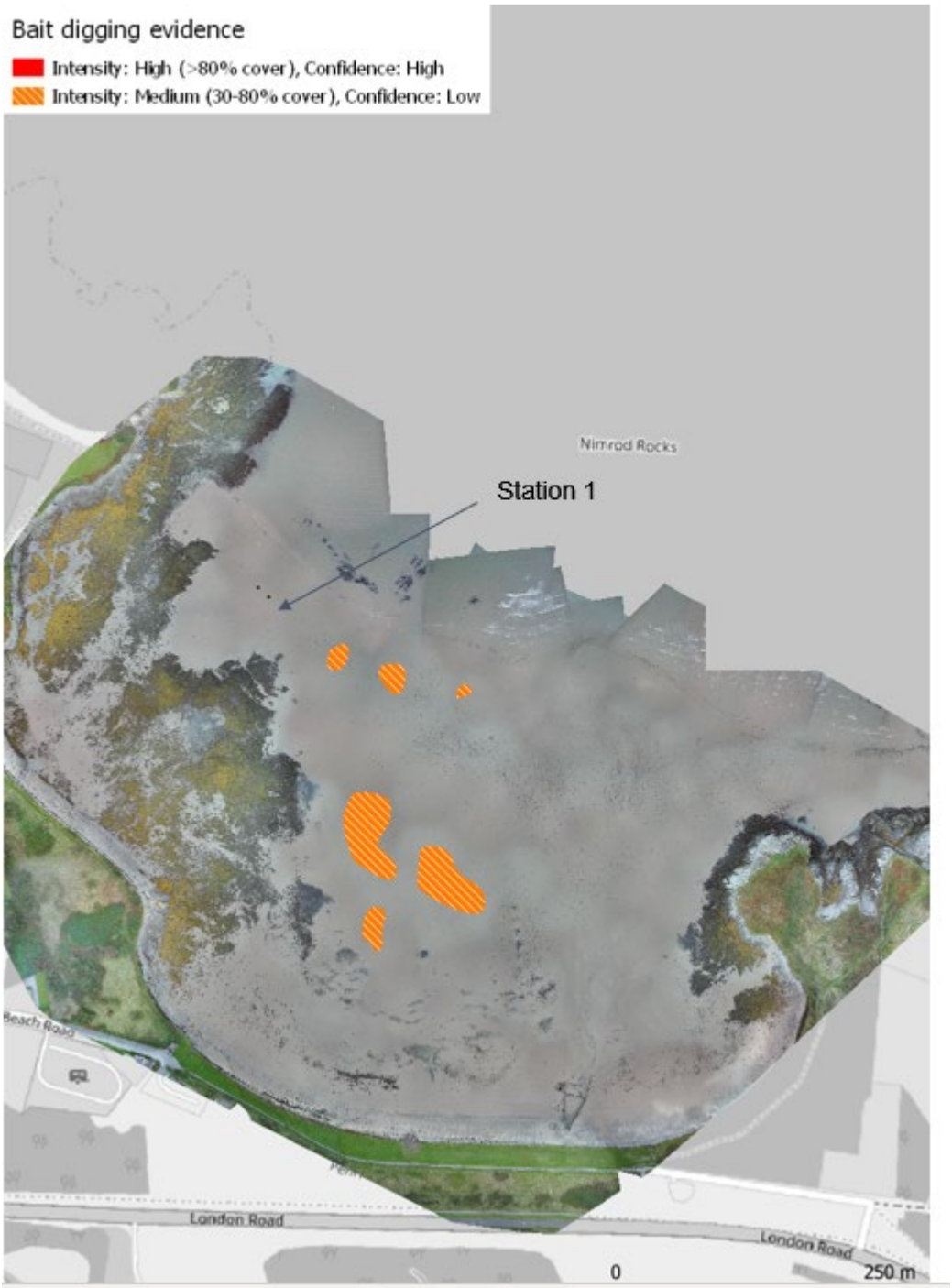


Figure 29 - Bait digging mapped at Penrhos Beach. Heavy black borders of polygons indicate newly dug areas.

Shore Survey - Penrhos Beach, Holyhead

General description and accessibility

Penrhos Beach is a large open bay, accessed from the end of the no-through Penrhos Beach Road near Holyhead. Here a short footpath leads down to the shore from a car park. The sandier portions of the beach are partially protected by a series of rocky spurs and headlands. This area is moderately exposed to wave action (prevailing wind offshore but onshore wind frequent), but gains some shelter from the land mass of Holy Island to the west and the main Holyhead Breakwater to the NW, although wind and wave action from the north would impact directly on this shore.

Figure 30 - The control holes dug in medium fine rippled sand 02/10/2019.

Bait digging distribution

There was no bait digging activity observed here during the site visit in October 2019 and the mobile nature of the sandy sediments would quickly collapse any evidence of digging after only one or two tidal cycles. The firm sand had *Arenicola marina* casts on some of the mid-shore areas which are presumably targeted by bait diggers. There were no features, such as shallow, water-filled pools, in the sediment that might indicate previous bait digging activity. It was decided to lower the priority of a second visit to this site because of the predicted very limited persistence of signs of digging activity.

Figure 31 - Control hole with an indistinct subsurface RPD layer.

Habitat

The sandy sediment in the area where the control holes were dug comprised firm, rippled sand with a sub-surface indistinct RPD layer 10 cm deep. Nearby bedrock at the same level on the shore supported *Fucus serratus* (corresponding to lower middle shore). The sediment supported *Arenicola marina* and other small polychaetes, and although not sampled in detail, would correspond with one of the cleaner, less muddy biotopes in the Level 4 JNCC biotope complex *LS.LSa.MuSa Polychaete/bivalve-dominated muddy sand shores*.

Spatial variability observed

There was very little spatial variability in the distribution of sediment habitats on the whole shore, although there were aggregations of *Arenicola marina* casts in the areas of more localised shelter.

Persistence of bait digging

The trial holes at this site were not re-visited so no information on the degree of persistence of the holes could be gained. However, based on knowledge of shores with similar sediment characteristics, it was considered unlikely that signs of bait digging persist beyond a few tidal cycles due to the semi-mobile and relatively coarse nature of the sands in this area.

Issues encountered

As with the other stations in north Wales sampled during the autumn and winter, low water of spring tides corresponded to poorly-lit times of day which limited the quality of aerial and ground-based images.

3.3 Beddmanach Bay

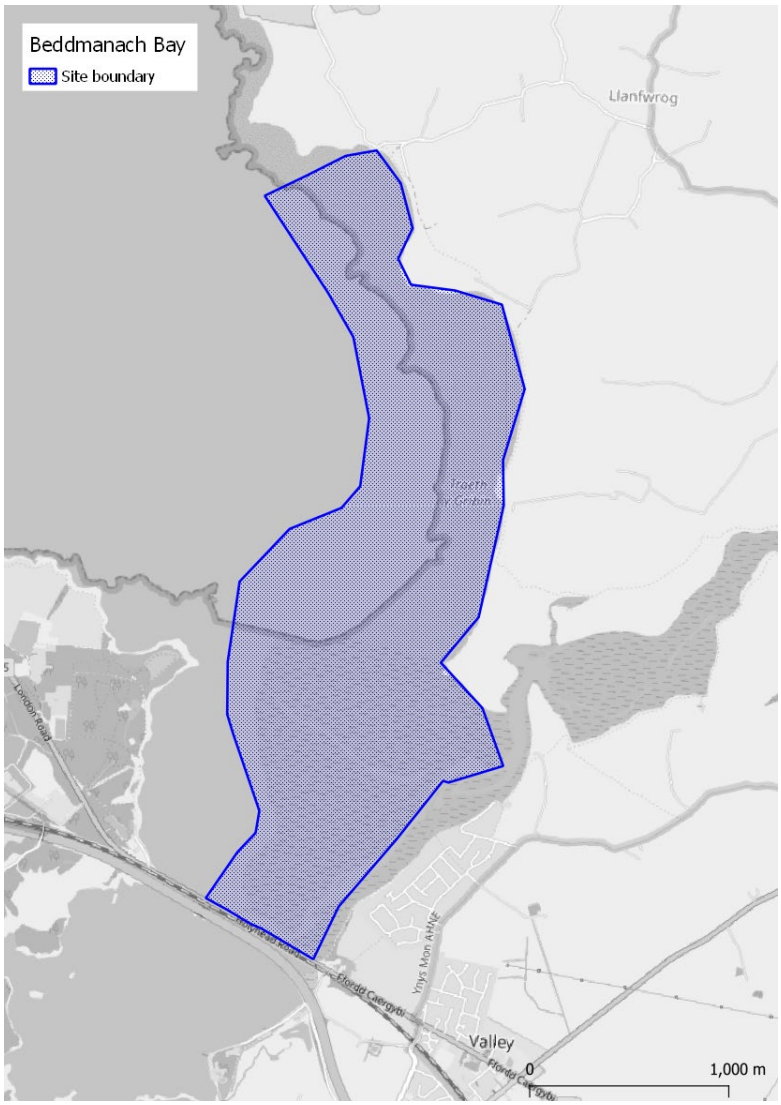


Figure 32 - Survey area - Beddmanarch Bay

Table 8 - Beddmanarch Bay visit summary

Category	**Information about site surveyed**
Date(s) of flight	28/10/2019
Time(s) of flight	1352-1603
Local LW time	1603 (Holyhead)
Field report	20191030 field report bait digging Foryd Beddmanarch.docx 20191110 field report Neubwll Four Mile Beddmanarch bait RH.docx
Tiled image file	BeddmanarchNorth_28102019.tif BeddmanarchCentre_28102019.tif BeddmanarchSouth_28102019.tif
Control stations and habitat(s) observed	**Station 1** - (The Cob) - SH 28376 79973 Fine sandy mud with *Hediste* and *Scrobicularia* and small polychaetes. Sticky consistency and black layer immediately below surface. **Station 2** – (Gorad Rd) - SH 28642 80240 Fine sandy mud with coarse gravel sub-layer with king ragworm *Alitta virens*. Cobbles and boulders nearby with *Fucus vesiculosus* and *Ascophyllum nodosum*.
Shore exposure	Moderately exposed (outer bay) to very sheltered (Cob area)
Area of site	336 ha
Bait diggers observed	One bait digger seen just south of Station 2. No backfilling observed.
Target species	**Station 1:** *Alitta virens* (King ragworm), Ragworm **Station 2:** *Alitta virens* (King ragworm), Ragworm, (*Carcinus maenas* – peeler crab refuge traps)
Date of follow up visit	10/11/2019 (13 days), 21/12/2009 (54 days), 04/03/2020 (128 days)

Mapping Beddmanarch Bay

Table 9 - Area in m² of bait digging evidence mapped on Beddmanarch Bay, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	19	303
Medium	12,908	13
Low	26	No data
Very low	No data	No data
Total	12,953	316

Medium intensity

Confidence	Old (age)	New (age)
High	2,073	396
Medium	89,050	No data
Low	107,535	No data
Very low	43,511	No data
Total	242,169	396

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	1,288	No data
Low	2,174	No data
Very low	242	No data
Total	3,704	0

Total dug old and new

Old (age)	New (age)	Combined
258,826	712	259,537

A total of 712 m² of new and c.26 ha of old evidence of bait digging was mapped at Beddmanarch Bay. Overall this covered less than a tenth of the site.

Some of the imagery for Beddmanarch Bay was of poor quality due to a combination of low light and insufficient identifiable keypoints, making it difficult or impossible to accurately identify evidence of bait digging in these areas. This issue mainly affected the northern third of the site (Figure 33). Aerial imagery cover of Beddmanarch Bay was also incomplete near the mouth of the river Alaw. The blurry and incomplete imagery may have impacted the amount of bait digging evidence mapped, as mainly very low confidence evidence was mapped in this area.

Some of the north end of Beddmanarch Bay was also covered by the sea at the time of flying. No evidence of bait digging was found near this area, so it is unlikely that any was obscured by the high water.

Evidence of bait digging at Beddmanarch Bay was concentrated from the mouth of the river Alaw south to the Stanley Embankment, in some parts of which evidence was intense. Smaller amounts of evidence occurred at the north end of the site, with a couple of isolated patches in the middle.

5,680 m² of the area mapped as low or very low confidence near the mouth of the river Alaw was thought to be potentially natural patterning in the sediment rather than artificial disturbance caused by bait digging. The impact of this on the overall results is minimal.

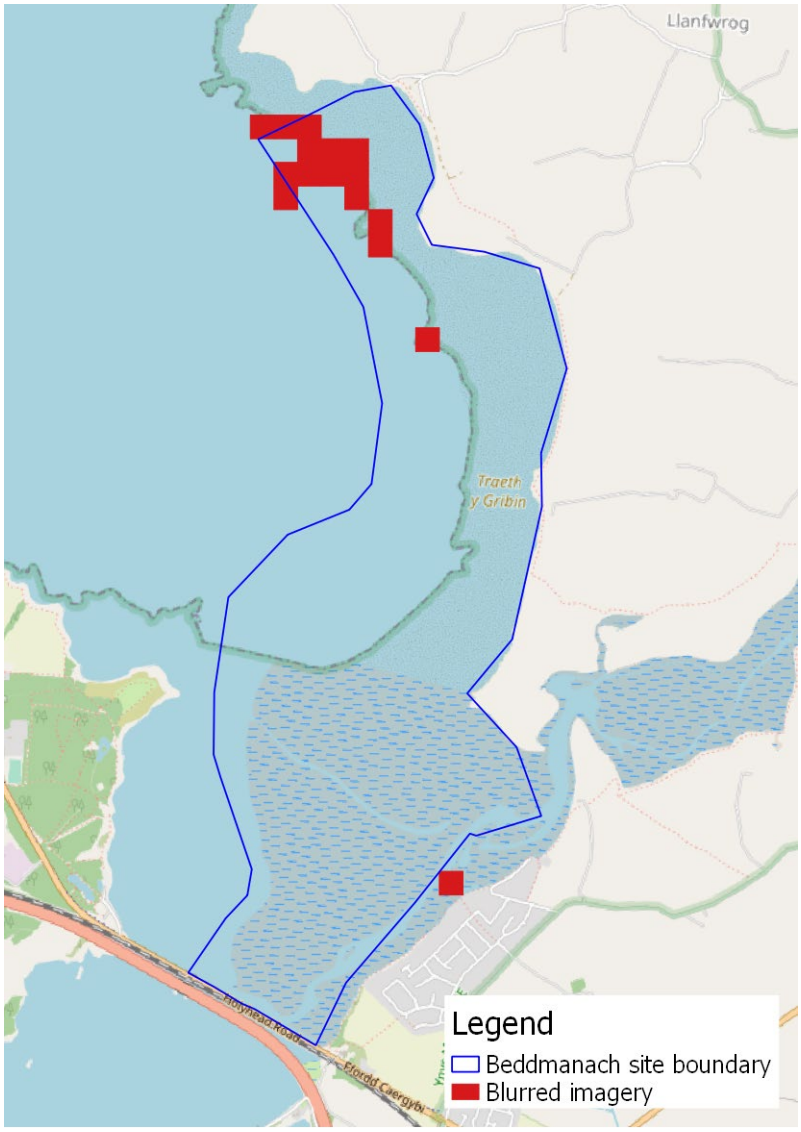


Figure 33 - Approximate location of blurred aerial imagery at Beddmanarch Bay

Figure 34 - Bait digging - Beddmanarch Bay (North). Heavy black borders of polygons indicate newly dug areas.

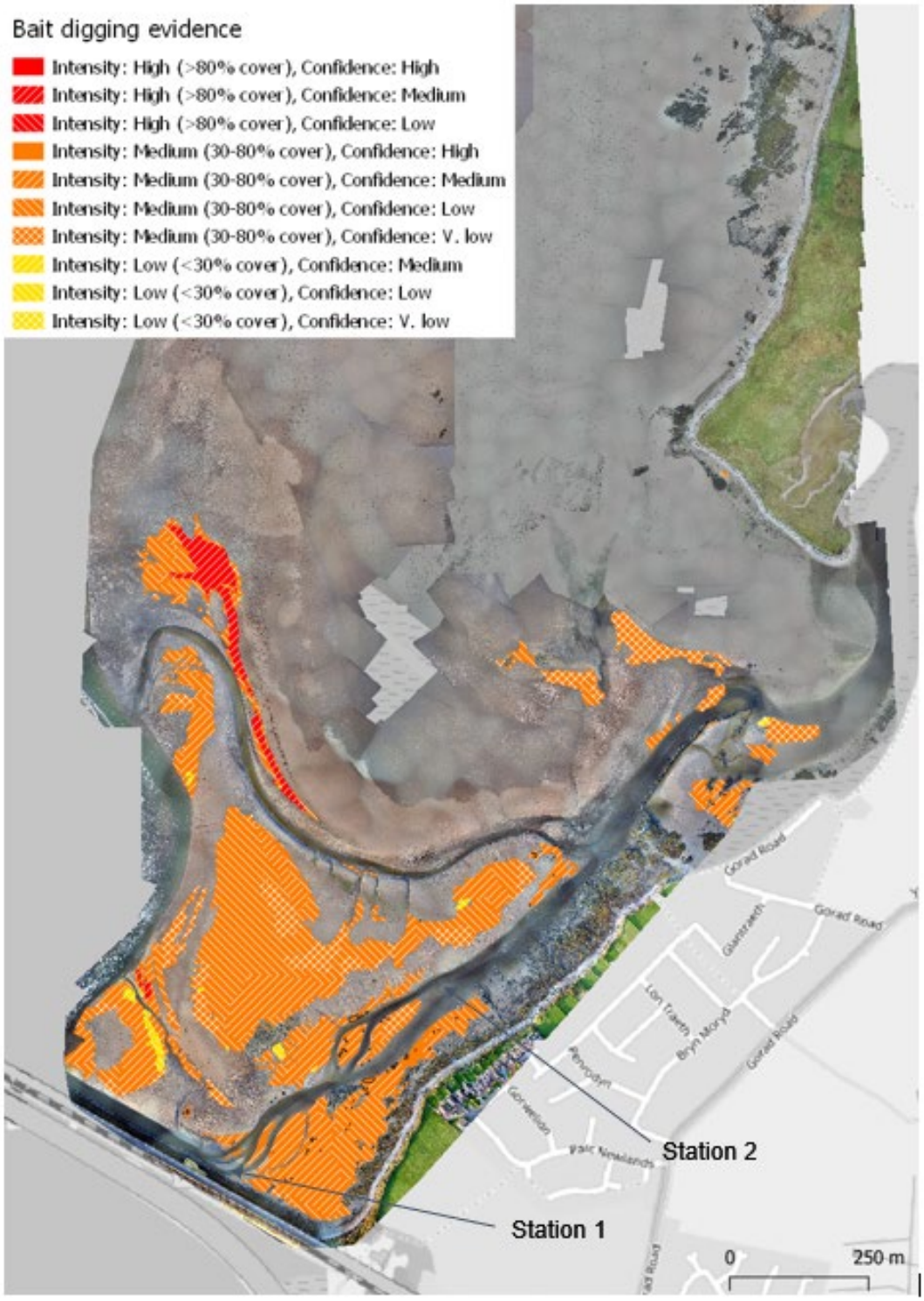


Figure 35 - Bait digging - Beddmanarch Bay (South). Heavy black borders of polygons indicate newly dug areas.

Shore survey - Beddmanarch Bay (Station 1), Gorad Rd, Holyhead

General description and accessibility

Beddmanarch Bay is a large open area of sandy and muddy sediment flats that extend approximately 3 km NE of the Cob causeway where the A5 and A55 roads link Holy Island with the rest of Anglesey. The coarser and more mobile sediments to the NE of the area were surveyed by aerial photography only. Wave-exposure into Beddmanarch Bay varies from moderately exposed in the outer parts of the bay to very sheltered adjacent to the Cob causeway. The area targeted for digging control holes was in the more wave-sheltered SE corner of the bay at two stations, both of which were accessed from Newlands Park off Gorad Rd near Valley, Holyhead. This shore station was accessed via a footpath from Gorwelion Rd then turning right (NE) along the shore towards a perpendicular line of boulder (which appeared to be the remains of a wall). The shore was backed by clean cobbles and boulders at the base of a steep bank, followed by fucoid-covered bedrock and boulders leading on to mixed muddy sand and gravel plain adjacent to a tidal channel. A second station was chosen for digging control holes adjacent to the Cob causeway (see Station 2).

Figure 36 - Panoramic image of the shore below the Newlands Park housing development.

Bait digging distribution

Bait digging activity and signs of bait digging were seen in the muddy sand patches that occur between the areas of fucoid-covered bedrock and boulders along the whole shore in front of Newlands Park from Gorad Rd (where it runs next to the shore) towards the Cob. The sediment here was muddy fine sand with stone and shelly gravel and retained signs of previous digging activity as contiguous shallow pits, footprints and water-filled depressions often with the remains of adjacent spoil heaps. Although difficult to separate the signs of digging from general disturbance it was estimated that there was approximately 1 hole every 4 m^2.

Habitat

The mixed muddy sand and gravel sediment where the control holes were dug supported large king ragworm *Alitta virens* (the target species for the bait diggers), *Hediste diversicolor* and various other smaller polychaetes. The biotope JNCC level

4 complex includes such species and habitat in *LS.LMx.GvMu Hediste-dominated gravelly sandy mud shores*.

Figure 37 - Control hole in muddy sand with a gravel sub-layer.

Figure 38 - *Alitta virens* in the control hole.

Spatial variability observed

Much of the sediment along this stretch of shore appears to be dug for bait although is probably more restricted to the sediment on the landward side of the water channel that runs parallel to the shore in the area adjacent to the control holes.

Persistence of bait digging

The apparently stable nature of the muddy sediments in this area is now known to retain evidence of topographical disturbance for months, although the deep holes and tall spoil heaps of mixed sediment from the control holes was partially smoothed after a few days. The initial observations were made and control holes were dug at the end of October 2019 and the last observations made 128 days later in March 2020. During that time the general appearance of the whole area of shore adjacent to the control holes changed little, although the control holes themselves were far less distinct, but still identifiable, at the end of this period. One feature of this control station and the adjacent one nearer the Cob is that fucoid-covered cobbles, that get moved around by wave action, got 'caught' in the control holes. This presumably prevents the sediment from recovering to its previous pre-dug state as the algae attached to the stones maintains the hollowed shape by scour action. This phenomenon must be widespread in areas with fucoid boulder and cobble habitats adjacent to bait dug sediment.

Figure 39 - One of the control holes now with a fucoid-covered cobble in the remains of the hollow. The coarse material of the spoil heap is still apparent.

Issues encountered

As with the other stations in north Wales sampled during the autumn and winter, low water of spring tides corresponded to poorly-lit times of day which limited the time available to gather good quality aerial and ground-based images. Beddmanarch Bay aerial imagery had to be collected twice. A proportion of the images taken on the first attempt were out of focus due to water entering the lens. On the second attempt the light levels at the time of low water were too low to fly the whole area with one drone in the time available so a second aircraft was used simultaneously to complete the survey.

Shore survey - Beddmanarch Bay (Station 2), The Cob, Holyhead

General description and accessibility

As described above for Station 1, the area targeted for digging control holes at Station 2 adjacent to the Cob was in the more wave-sheltered SE corner of the bay. Access was from Newlands Park off Gorad Rd near Valley, Holyhead. This shore station was accessed via a footpath from Gorwelion Rd then turning left (SW) along the shore towards the Cob A5/A55 causeway. The shore was backed by the fucoid-covered sloping Cob wall and fucoid-covered boulders and cobbles leading onto fine sandy mud adjacent to the tidal channel. The culvert that joins Beddmanarch Bay to the Inland Sea flows through the Cob about 500 m from this station.

Figure 40 - Panoramic image of the control station in relation to the Cob causeway.

Bait digging distribution

Bait digging activity and signs of bait digging were seen in the muddy sand patches that occur between the areas of fucoid-covered bedrock and boulders along the whole shore in front of Newlands Park towards the Cob. The sediment here was muddy fine sand with stone and shelly gravel and retained signs of previous digging activity as contiguous shallow pits, footprints and water-filled depressions often with the remains of adjacent spoil heaps at a density of approximately 1 per 4 m^2. Closer to the Cob wall, where the control holes were situated, the sediment had a higher proportion of mud and fewer signs of bait digging holes.

Crab tiles / gutters

In addition, there were lines of c 40 cm sections of plastic guttering, inverted and pushed into the sediment at an angle as peeler crab refuge traps (Figure 41). These were arranged in lines along the small creeks and water channels on the shore and was estimated to total over 200. There were footprints in the mud following the lines of refuges, presumably as a result of collecting the peeler crabs that gather under them.

These are identifiable from the aerial photographs (Figure 42) once ground truthing had established their identity.

Figure 41 - Panoramic photograph showing fine sandy mud adjacent to control holes with peeler crab refuge pipes along creek.

Figure 42 - The Cobb, SE side of Beddmanarch Bay. The red arrows indicate some of the areas where sections of plastic gutter have been inserted into the sediment in lines near to or in water channels to create peeler crab (moulting *Carcinus*) refuges

Habitat

The fine sandy mud in the area adjacent to the control holes was not sampled in detail for its infauna but various species including *Scrobicularia plana*, *Hediste diversicolor*, and other small polychaetes were noted. These species and the nature of the muddy sediment are included in the JNCC Level 4 biotope complex *LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores*.

Spatial variability observed

Signs of bait digging were more obvious in the gravelly mud along the shore line rather than near to the cob wall where the sediment had an increasingly larger proportion of soft mud.

Persistence of bait digging

The muddy sediment in this area is now known to retain evidence of topographical disturbance for months, although the deep holes and tall spoil heaps of muddy sediment from the control holes was partially smoothed after a week. The initial observations were made and control holes were dug at the end of October 2019 and the last observations made 128 days later in March 2020. During that time the general appearance of the whole area of shore adjacent to the control holes changed little, and although the control holes themselves were slightly less distinct, they were easily identifiable at the end of this period. One feature of this station is that *Ascophyllum nodosum*-covered cobbles, that get moved around by wave action, got pushed into and 'caught' in both the control holes. This presumably prevents the sediment from recovering to its previous pre-dug state as the algae attached to the stones maintains the hollowed shape by scour action. This phenomenon must be widespread in areas with fucoid boulder and cobble habitats adjacent to bait dug sediment.

The other man-made features in the sediment at this station, such as footprints around the many peeler crab refuge traps, were similarly persistent and showed no sign of change for the duration of this work (128 days).

Figure 43 - One of the control holes dug 28/10/2019.

Figure 44 - The control holes 128 days later on 04/03/2020. Both holes (second is in the background) have *Ascophyllum nodosum* covered cobbles in them. The spoil heap is still apparent on the right of the hole.

Issues encountered

As with the other stations in north Wales sampled during the autumn and winter, low water of spring tides corresponded to poorly-lit times of day which limited the time available to gather good quality aerial and ground-based images. As mentioned above, the Beddmanarch Bay aerial imagery had to be collected twice to correct for a problem with condensation in the drone's lens. A second aircraft was used simultaneously to complete the survey of the extensive Beddmanarch Bay area.

3.4 Four Mile Bridge

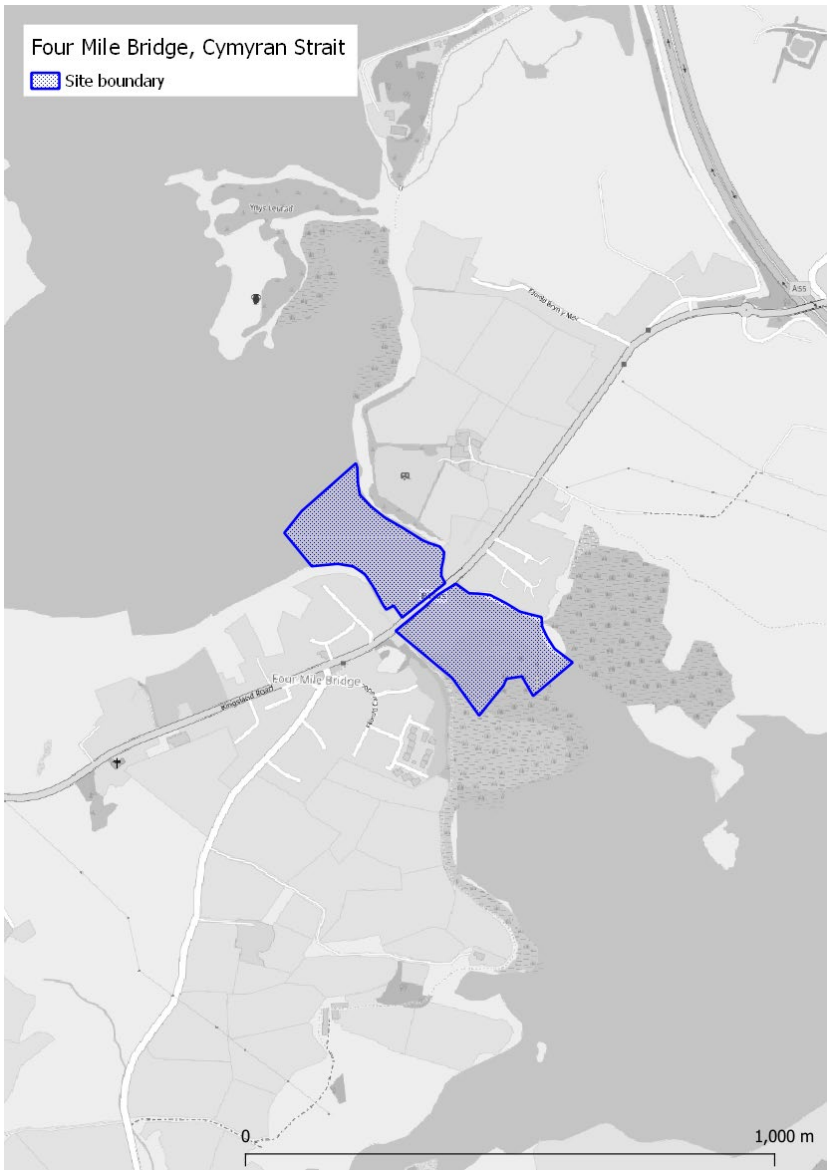


Figure 45 - Survey area Four Mile Bridge. Note only the area to the south of the bridge was surveyed.

Table 10 - Four mile bridge visit summary

Category	Information about site surveyed
Date(s) of flight	10/11/2019
Time(s) of flight	1352-1603
Local LW time	1459 (Holyhead)
Field report	20191110 field report Neubwll Four Mile Beddmanarch bait RH.docx
Tiled image file	FourMileBridge_20191110.tif
Control stations and habitat(s) observed	**Station 1** - SH 28093 78290 Hole dug in soft muddy sand with a coarse gravel sub-layer. Some *Arenicola* casts present and *Hediste diversicolor* and *Alitta virens* in the sediment. Second hole dug in poorly sorted sandy, muddy gravel with pebbles with *Hediste*. LS.LMx Littoral mixed sediment
Shore exposure	Ultra sheltered
Area of site	4 ha
Bait diggers observed	One – using fork. No backfilling observed.
Target species	*Alitta virens* (King ragworm), Ragworm
Date of follow up visit	04/03/2020

Mapping Four Mile Bridge

Table 11 - Area in m² of bait digging evidence mapped on Four Mile Bridge, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	11	200
Medium	1,262	No data
Low	No data	No data
Total	1,274	200

Medium intensity

Confidence	Old (age)	New (age)
High	353	329
Medium	1,023	No data
Low	62	No data
Total	1,439	329

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	No data	No data
Low	No data	No data
Total	0	0

Total dug old and new

Old (age)	New (age)	Combined
2,712	528	3,240

The aerial imagery at Four Mile Bridge was limited to the area SE of the bridge, as sea levels were much higher to the NW of the bridge with little exposed sediment. A total of 528 m² of new and 2,712 m² of old evidence of bait digging was mapped at Four Mile Bridge. Overall this covered less than a tenth of that part of the site southeast of the bridge.

Compared with other sites, the evidence of bait digging at Four Mile Bridge was distinct, with only 62 m² of low confidence evidence mapped out of a total of 3,240 m^2. Where it occurred, evidence also tended to be intense and the percentage of new evidence was relatively high (16%). This may suggest that bait digging is frequent and intense at Four Mile Bridge, but either the evidence does not last long or areas are frequently re-worked.

The aerial photography showed one bait digger retreating from recently dug holes (Figure 46).

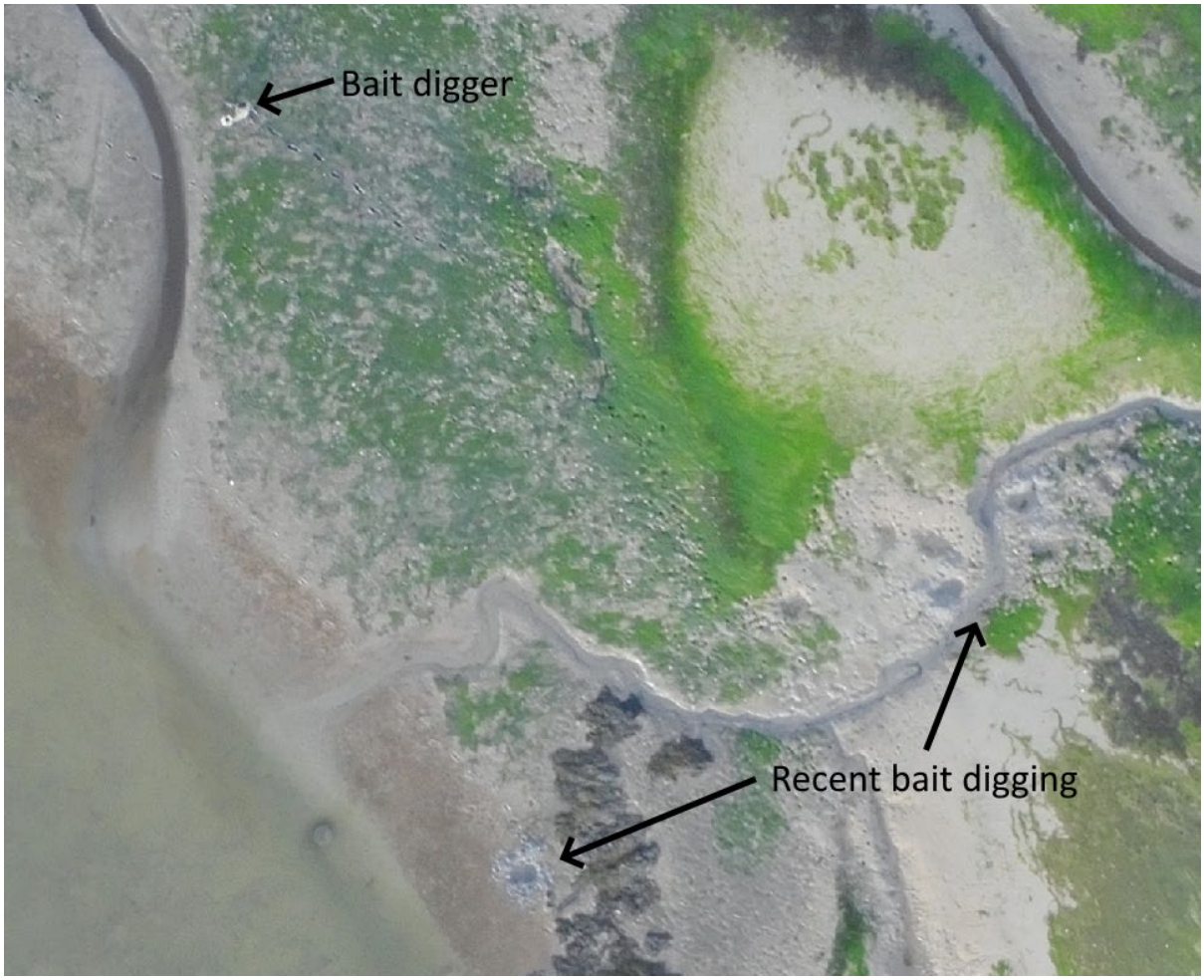


Figure 46 - Bait digger (top left) retreating from evidence of recent bait digging at Four Mile Bridge.

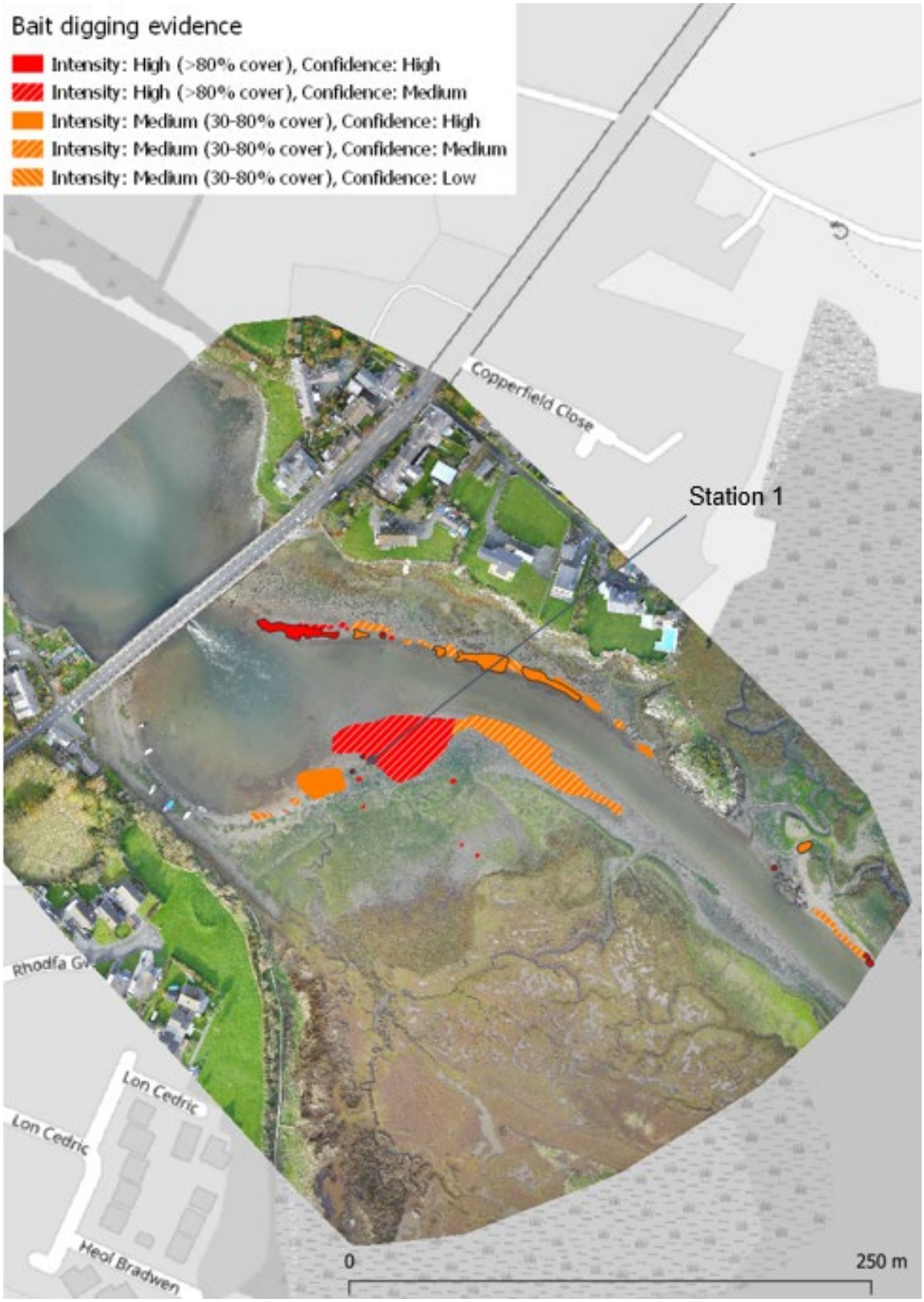


Figure 47 - Bait digging - Four Mile Bridge. Heavy black borders of polygons indicate newly dug areas.

Shore Survey - Four Mile Bridge, Cymyran Strait

General description and accessibility

Four Mile Bridge is a small village with a short bridge that carries the B4545 road across the Cymyran Strait at the southern end of the Inland Sea. The culvert underneath the bridge forms a tidal rapid on the incoming and outgoing tides and restricts the rise and fall of the tide in the water body on the NW side of the bridge but experiences near normal rise and fall on the SE side. The area is ultra-sheltered to wave action but the tide is accelerated under the road bridge. Access to the shore on the SE side is a short walk from either side of the bridge onto the saltmarsh and muddy sandy gravel intertidal habitats. There are a few boats moored on the SE side and bait digging activity is regularly seen here.

Figure 48 - Test hole dug in gravelly mixed sediment near to the current-washed edge of the channel at Four Mile Bridge. This whole area has been heavily dug and the coarse nature of the sediment permanently retains a very three-dimensional topography.

Bait digging distribution

Intensive bait digging activity is concentrated on the muddy gravels to the SE side of the bridge as shown on the aerial orthomosaic (Figure 47). The intensity of hole digging is at least 1 hole per m^2 along the banks of the channel and probably more on the spit that faces the outflow from the culvert accessed via the south bank of the channel. Here the muddy gravels have been continuously overturned by repeat digging activity to such an extent that the finer muddy fractions appear to have been winnowed away by the accelerated tidal flow. The relatively heavy-weight coarse gravel is not moved or flattened by the tidal flow which results in a permanently cratered landscape of over a few hundred square metres in area.

Habitat

The coarser mixed muddy sediment at this location are dug for ragworm and king ragworm, but this area rapidly grades to finer mixed muddy gravels and sand away from the area of strong tidal flow and intensive bait digging. This area is likely to be characterised by the biotopes in the littoral mixed sediment Level 3 complex *LS.LMx Littoral mixed sediment* but would need further infaunal sampling to determine individual biotopes.

Spatial variability observed

Bait digging on the SE side of the bridge appears to be largely concentrated in the fairly small area on the south bank opposite the culvert and on the north bank close to the bridge. The density of holes and signs of activity continues in a strip down both sides of the channel for around 100 m and there is also a small patch of dug sediment below the saltmarsh a further 100 m SE of the group of houses near the bridge.

Persistence of bait digging

The main problem with determining the longevity of the control holes was finding them amongst the intensively worked muddy gravel. By aligning features in photographs and using GPS coordinates the approximate locations were re-photographed. The images show holes that are at the same location, but it is not possible to determine whether these are the original or newer holes dug at the same spot on a later date. It would seem that if left untouched the dug features in the coarse gravel at this site would persist for many months or even years as finer sediment would need to re-accumulate and there is little or no wave action to smooth the sediment surface.

Figure 49 - One of the original control holes in the muddy gravel. Note the green ephemeral algae on the tops of the sand covered mounds.

Figure 50 -Cymyran Strait just SE of Four Mile Bridge 3/3/2020. Although this is the exact location of the test hole dug 10/11/2019, it is not possible to determine whether this hole is the same one. Bait digging activity was seen on 3rd and 4th March 2020 at this location and the whole area is heavily, and apparently constantly, being worked. The green algae seen on the previous visit has now gone.

Issues encountered

This site is within the flight exclusion zone at RAF Valley and special permission is required for drone flights when the airfield is non-operational at weekends. DJI flight controller software automatically prevents take-off and would require manufacturer's unlocking for flights to go ahead. This project managed to fly the area with appropriate permissions before the law changed.

3.5 Inland Sea

This area was not able to be mapped as the tide rarely empties from this area and there are restrictions from RAF Valley airfield meaning that an opportunity to fly the UAV was not possible. A foot survey was completed instead.

Shore survey - Inland Sea, Cymyran Strait

General description and accessibility

The Inland Sea is the section of the Cymyran Strait between the culverts that run under the A5 / A55 bridges and the road bridge at Four Mile Bridge. Tidal level in the Inland Sea is kept artificially high by the restricted flow through these culverts and salinity levels are below full-strength sea water. The area accumulates seawater during high amplitude spring tides when there is insufficient time for it to empty between each successive high water. During low amplitude neap tides, the water level falls to expose a broad area of intertidal sediment flat in the embayment south of Ynys Leurad.

Bait digging distribution

The area was surveyed on foot during neap tides on 3rd March 2020. The sediment flat throughout the targeted embayment appears to be highly marked with shallow depressions, similar in size to bait-dug holes seen elsewhere. However, the sediment inside and between these depressions is cohesive, fine, muddy sand bound firmly together by a mixture of filamentous algae and/or *Zostera noltei*. Small areas approximately 0.5 -1 m diameter were found where this fibrous-sediment matrix had been abraded to reveal more mobile sediment underneath. A few such abraded areas were found in the channel NW of the bridge and scattered around the margin of the embayment, although whether these were natural or a result of bait digging is unknown.

Figure 51 – Inland Sea 03/03/2020 The sediment comprises a stable mix of fine sand and mud bound by a mix of filamentous algae and *Zostera noltei*. There are many water-filled depressions. Whether these are evidence of bait digging is debateable as most of the depressions were lined with *Zostera* and filamentous algae and are therefore probably years old and/or are formed naturally.

Habitat

The habitat and species observed are described in the JNCC Level 5 Biotope *LS.LMp.LSgr.Znol Zostera noltei beds in littoral muddy sand*. The *Zostera noltei* observed during this time of year was probably seasonally diminished and will develop new shoots in the spring and summer.

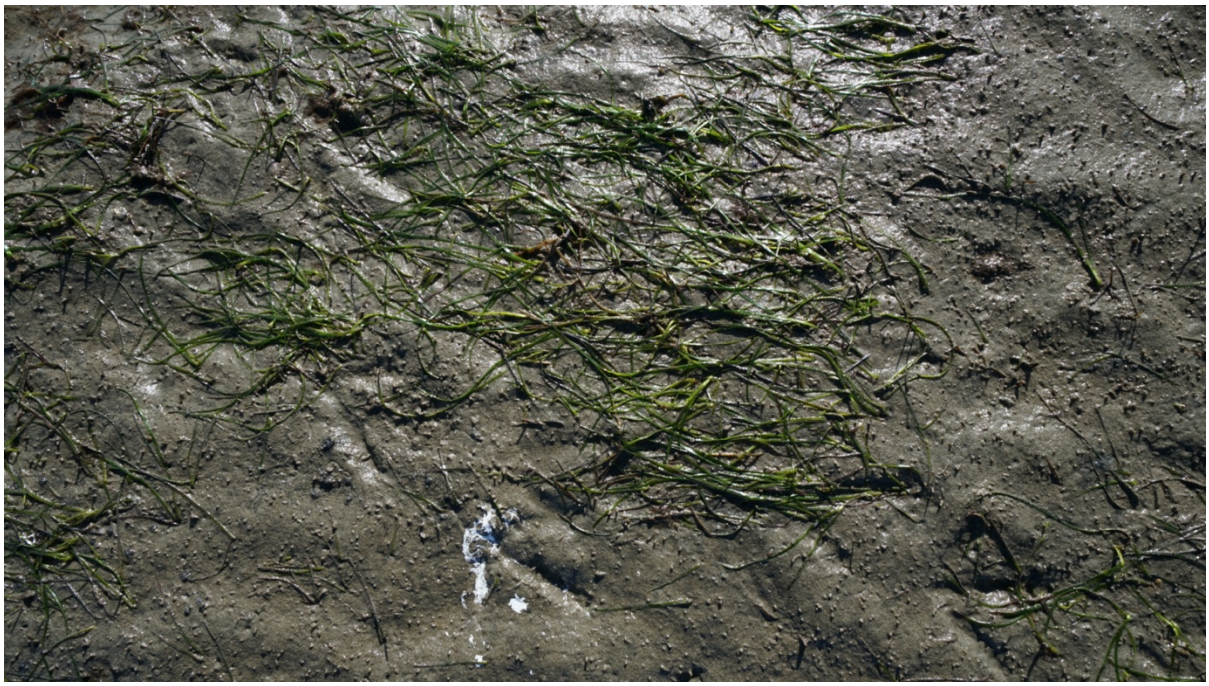


Figure 52 - Inland Sea 03/03/2020. *Zostera noltei* and filamentous algae binding the sediment surface together.

Spatial variability observed

Whether any of the observed pitting and depressions in the sediment surface are as a result of bait digging is unclear, but the size and extent of the pitting varies throughout this area. Larger and deeper indentations were seen on the north shore of the bay adjacent to the saltmarsh but these, like the others in the area, were lined with filamentous algae and/or *Zostera noltei* which probably takes at least one or two years to form the dense fibrous sand-binding mats that holds the sediment together.

Figure 53 - Inland Sea 03/03/2020. Sediment consolidated by filamentous algae, adjacent to saltmarsh, appear very pitted, although the pools here are also lined with filamentous algae and *Zostera noltei*.

Persistence of bait digging

Holes made through the algal-*Zostera* mats might take several seasons to repair naturally. Whether such features are more widespread within the Inland Sea is unknown from the current visit. Aerial survey would help reveal such features on the sediment flats at low water and when shallow water just covers the sediment flats.

Figure 54 - Inland Sea 03/03/2020. Where the surface bound sediment has been damaged holes are lined with mobile sediment and appear very different from the rest of the habitat. Very few such holes were found in the areas investigated.

Figure 55 - Inland Sea 03/03/2020. The area just north of the causeway at Four Mile Bridge was still covered by shallow water during the survey. There are a few patches of disturbed sediment in this region that might be evidence of bait digging which occurs when the tide drops in this area – perhaps during the most pronounced neap tides of the year.

Issues encountered

Accurately predicting when the sediment flats are uncovered by the tide was the main problem with attempting survey at this location. Previous visits, timed to coincide with low water of neap tides at Holyhead plus a two-hour delay, found the tide almost fully in. Atmospheric conditions – low pressure, high winds and heavy rain – possibly combine to keep the water levels in the Inland Sea unpredictably high.

Predicting low water in the Inland Sea to coincide with weekends, when aerial survey by drone may be allowed by RAF Valley, and within daylight hours and with calm weather proved to be beyond the scope of the project at the time of year.

3.6 Llanfair yn Neubwll

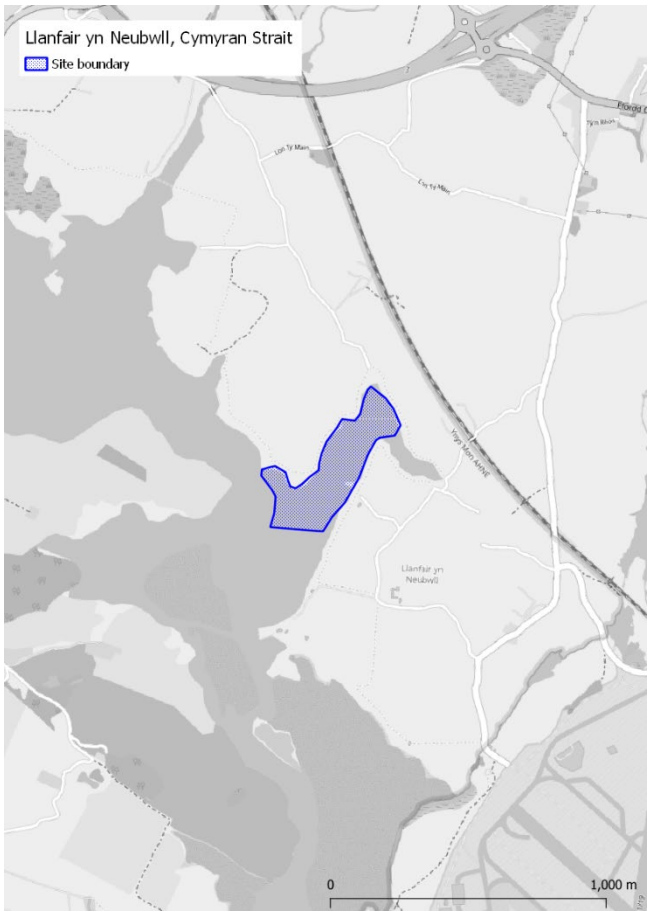


Figure 56 - Survey area - Llanfair yn Neubwll

Table 12 - Llanfair yn Neubwll visit summary

Category	**Information about site surveyed**
Date(s) of flight	10/11/2019
Time(s) of flight	1304-1620
Local LW time	1459 (Holyhead)
Field report	20191110 field report Neubwll Four Mile Beddmanarch bait RH.docx
Tiled image file	LlanfairYnNeubwll_20191110.tif
Control stations and habitat(s) observed	**Station 1** - SH 29622 77148 Soft, sticky sandy mud with surface water and a covering of filamentous algae and patches of small *Zostera noltei*. *Arenicola* casts and *Scrobicularia* shells present. *LS.LMp.LSgr.Znol Zostera noltei beds in littoral muddy sand* is a good fit for much of the habitat although the littoral sand Level 4 biotope complex *LS.LSa.MuSa*

Category	Information about site surveyed
	Polychaete/bivalve-dominated muddy sand shores probably applies to the areas without *Zostera* cover.
Shore exposure	Ultra sheltered
Area of site	9 ha
Bait diggers observed	None seen. But recent activity noted. No backfilling observed
Target species	Lugworm, King ragworm, Ragworm
Date of follow up visit	03/03/2020

Mapping Llanfair yn Neubwll

Table 13 - Area in m² of bait digging evidence mapped on Llanfair yn Neubwll, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	34	113
Medium	2,821	No data
Low	26	No data
Very low	No data	No data
Total	2,881	113

Medium intensity

Confidence	Old (age)	New (age)
High	96	840
Medium	10,499	19
Low	22,358	No data
Very low	12,854	No data
Total	45,807	859

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	No data	No data
Low	No data	No data
Very low	No data	No data
Total	0	0

Total dug old and new

Old (age)	New (age)	Combined
48,688	972	49,660

A total of 972 m² of new and c.5 ha of old evidence of bait digging was mapped at Llanfair yn Neubwll (Figure 58). Overall this covered about half of the site, but some of the areas mapped were outside of the site boundary.

All the visible evidence of bait digging was either high or medium intensity. Approximately 1.3 ha of the medium intensity evidence was considered to be very low confidence because it was unclear from both digitisers and site surveyors whether the patterning visible in the sediment was natural or artificial.

A surveyor was visible on the aerial photography near the test holes, largely apparent due to the shadow cast.

Figure 57 - A surveyor visible on the aerial photography for Llanfair yn Neubwll. This demonstrates the level of difficulty in identifying objects, including people, on even high resolution aerial imagery, as without a distinct shadow and footprints the surveyor would have looked very similar to the nearby rocks.

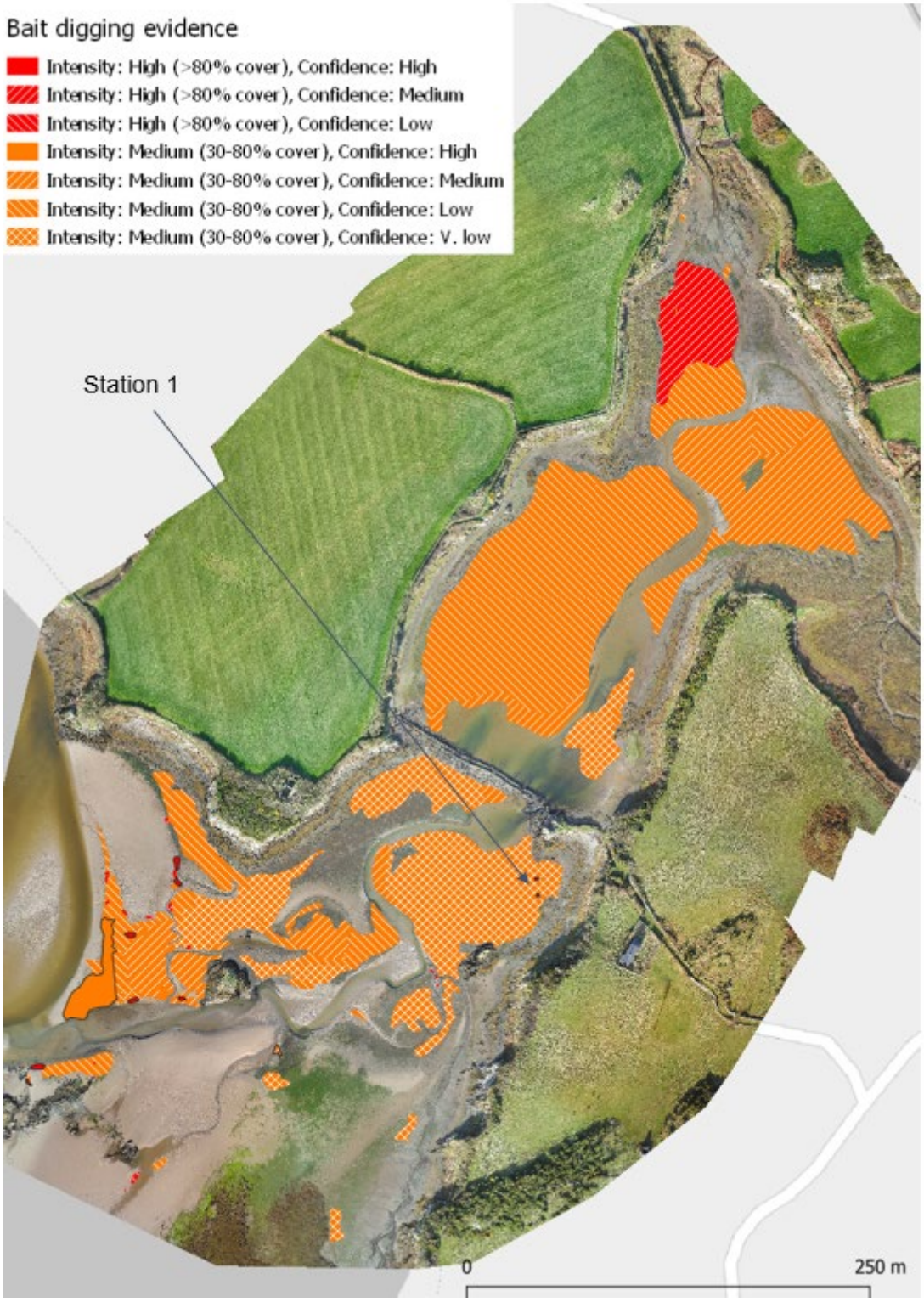


Figure 58 - Bait digging - Llanfair yn Neubwll. Heavy black borders of polygons indicate newly dug areas.

Shore Survey - Llanfair yn neubwll, Cymyran Strait

General description and accessibility

The Cymyran Strait is a semi-natural water body that divides Holy Island from the mainland of Anglesey. It has three road crossings with culverts underneath them towards the northern end that restrict tidal flow, and opens through a natural channel at the south end, north of Rhosneigr adjacent to the RAF Valley airfield. Parts of the main channel are locally strongly tide-swept, but there are small, extremely sheltered (< 3 km fetch from any direction) to ultra-sheltered (fetch of few hundred metres or less) and shallow sections that are almost completely protected from wave action. This site, towards the south of the Cymyran Strait, was accessed via a small green lane, Lon Felin Wen, that leads from the minor road near Llanfair yn neubwll down to the shore. The shore is backed by consolidated cobbles and pebbles that lead down onto a variety of muddy gravels, mud and cleaner sand near to the channels. There are remains of an old causeway adjacent to this site which forms a lagoon which only empties on neap tides.

Figure 59 - Panoramic image showing the approximate position of the control holes and the old causeway to the right of the image.

Bait digging distribution

Areas of dug sand and muddy gravel were found during the survey of this area and are apparent in the aerial images Figure 58. The cohesive and very stable sediments with *Zostera noltei* near to the control holes have been dug occasionally (estimated less than 1 hole per 10 m x 10 m area), but the main and most heavily dug areas were in the muddy gravel beds, just north-east of the old causeway, and in the less stable fine sand adjacent to small islands and rock just south of the small promontory Penrhyn-hwlad. In both these localities, the holes were near-contiguous and density was difficult to assess but estimated at 0.5-1 per m^2.

Habitat

The habitat at the control holes was cohesive fine muddy sand with patches of *Zostera noltei* nearby. The Level 5 *Zostera noltei* biotope in the JNCC classification *LS.LMp.LSgr.Znol Zostera noltei beds in littoral muddy sand* is a good fit for much of the habitat, although the littoral sand Level 4 biotope complex *LS.LSa.MuSa Polychaete/bivalve-dominated muddy sand shores* probably applies to the areas without *Zostera* cover.

Further away from the control holes, the heavily worked muddy gravel habitat best corresponds to the biotopes in the Level 3 complex *LS.LMx Littoral mixed sediment* - infaunal samples would be needed to confirm individual biotopes.

Figure 60 - Llanfair yn neubwll 04/03/2020. The area to the east of the old causeway (seen in the background of this image) exposed at low water of neap tides showing mixed muddy gravel and sand area that appears to have been heavily dug. This area was NRW's original target site but was covered by water during spring tides when the aerial surveys were being conducted.

Spatial variability observed

It would appear that the bait diggers who visit this area target different species (Lugworm, King ragworm, Ragworm) on the variety of habitats present, resulting in patches of intense activity and larger areas with more limited damage noted.

Persistence of bait digging

The control holes at this location have retained much of their original structure despite being 115 days old. The combination of virtually no wave action and the cohesive nature of the fine sediment has resulted in little more than the rounding of the spoil heaps and holes. The standing water in the holes, mixed with trapped drift algae, appears to have become anoxic as the debris has decomposed. *Beggiatoa* bacterial mats have grown on the floor of the holes and over the fragments of seaweed. This will influence the infaunal components of the sediment within the holes.

The muddy gravel sediments to the NE of the old causeway also exhibit signs of having been heavily worked and the topography of this section of shore is likely to bear long-term scarring.

Bait digging activity was recorded by an individual as it occurred in the more mobile sediments near the main channel that runs through the Cymyran Strait and was

photographed opportunistically 24 hours later. The sediments here are likely to return to near normal state relatively quickly, although the aerial images of this section of shore show evidence of considerable working that must occur on a regular basis.

Figure 61 - Test holes in the soft sandy mud at Llanfair yn neubwll. Foreground with *Arenicola marina*, filamentous green algae and *Zostera* sp. Some indistinct remains of shallow depressions in the sediment possibly from footprints and old bait digging holes. This area is ultra-sheltered from wave action, and the test holes are likely to retain their structure in the cohesive sediment for considerable time as shown in Figure 62.

Figure 62 - Llanfair yn neubwll 03/03/2020. The test hole dug in extremely sheltered muddy sand on 10/11/2019 115 days earlier. Spoil heap and depression still visible. Drift seaweed and debris causing some anoxia in the sediment (the adjacent test hole in this pair, dug at the same time, was similarly still apparent).

Figure 63 - Llanfair yn neubwll 03/03/2020. Large bait holes a few minutes old in the cleaner sandier sediments adjacent to one of the small water channels (dug by unseen bait digger).

Figure 64 - Llanfair yn neubwll 04/03/2020. The same bait holes as in Figure 63, 24 hours after digging. The topography is much smoother and lower and the colour of the spoil heaps has lightened. The small water channel has now changed course slightly to fill the line of holes. This illustrates the diversity of sediment stability and persistence of features within a small area – the holes in Figure 61 are only about 150 m away and have lasted many months

Issues encountered

Predictability of the tides combined with weekend-only permission for flying drones limited opportunities to access NRW's original target sampling station to the NE of the old causeway in the Cymyran Strait at Llanfair yn neubwll. This area was deeply flooded at low water of spring tides during the first visit so the control holes were placed, instead, to the SW of the old causeway. Some of the areas in the Cymyran Strait require low water of spring tides to sample, whereas the area above the old causeway, and the Inland Sea itself, require low amplitude neap tides with a time lag of around 2-3 hours after low water in Holyhead.

Figure 65 - Panoramic mosaic showing the flooded lagoon area north of the causeway at Llanfair yn neubwll at low water of spring tide.This site is within the flight exclusion zone at RAF Valley (it is only 1.3 km from the north end of the runway). DJI flight controller software automatically prevents take-off at any time and would require manufacturer's unlocking for flights to go ahead. Unlocked drones can only be flown with permission and when the airfield is non-operational at weekends. This project managed to fly the area with appropriate permissions before the law changed.

3.7 Y Foryd

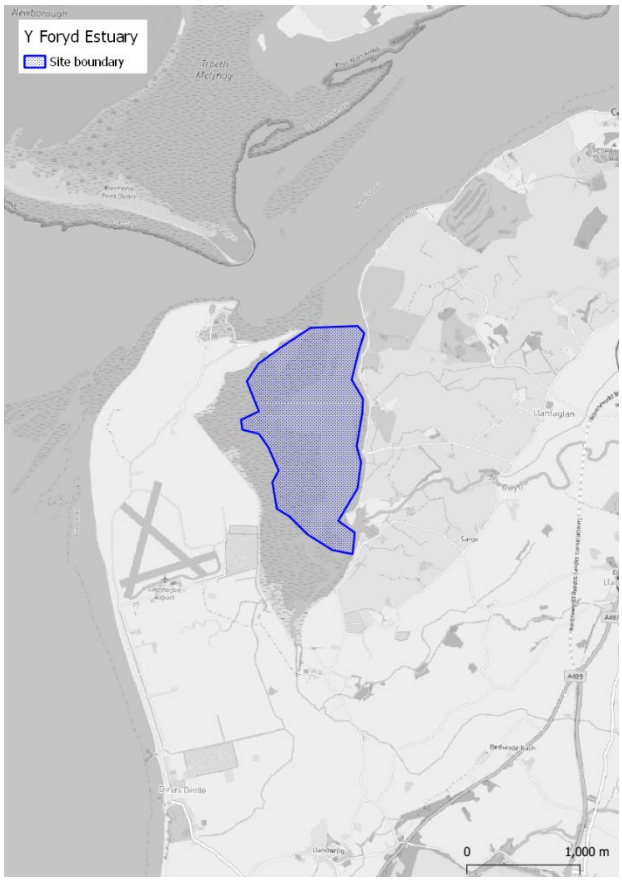


Figure 66 - Survey area - Y Foryd Bay, Caernarfon

Table 14 - Y Foryd Bay visit summary

Category	**Information about site surveyed**
Date(s) of flight	27/10/2019
Time of flight	1408-1458
Local LW time	1500 (Holyhead)
Field report	20191030 field report bait digging Foryd Beddmanarch.docx
Tiled image file	Foryd_20191027.tif
Habitat observed	**Station 1** - SH 45313 60216 Mid shore fine rippled sand with sub-surface black layer just below surface. *Arenicola* and *Cerastoderma* evident near the surface. *Scrobicularia* in areas of slightly finer mud. LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores and LS.LSa.MuSa Polychaete/bivalve-dominated muddy sand shores
Shore exposure	Very sheltered

Category	Information about site surveyed
Area of site	145 ha
Bait diggers observed	Three active. Digging and bait pumps. No backfilling observed
Target species	*Arenicola marina* seen. Bait diggers report Ragworm.
Date of follow up visit	10/03/2020 (135 days)

Mapping Y Foryd

A total of 69 m² of new and c.36 ha of old evidence of bait digging was mapped at Y Foryd Bay. Overall this covered about a quarter of the site.

Y Foryd Bay was challenging, as the appearance of bait digging evidence was different from other sites, the holes being smaller in general (maximum diameter of about 50 cm). This made the holes similar in size to those at Sandy Haven, but the sediment at Y Foryd Bay frequently made it difficult to distinguish bait digging from evidence of other disturbance, such as footfall outside mapped areas. It was possible to be confident that these were actual bait digging holes due to the presence of three active bait diggers southwest of the car park on the western side of the site (Figure 67).

Figure 67 - Active bait digging southwest of the car park on the western side of Y Foryd Bay. Three bait diggers are clearly visible due to their bright clothing and shadows. The newly dug holes in this area are unusually small, having a maximum diameter of about 50 cm.

Further uncertainty occurred at Y Foryd Bay due to patterns that could be old evidence of bait digging or natural. This applied to about a third of the area mapped.

The use of bait pumps was seen at Y Foryd Bay. After consideration of the (sub-3 cm resolution) aerial photography it was concluded that it was not possible to distinguish evidence of bait pump use.

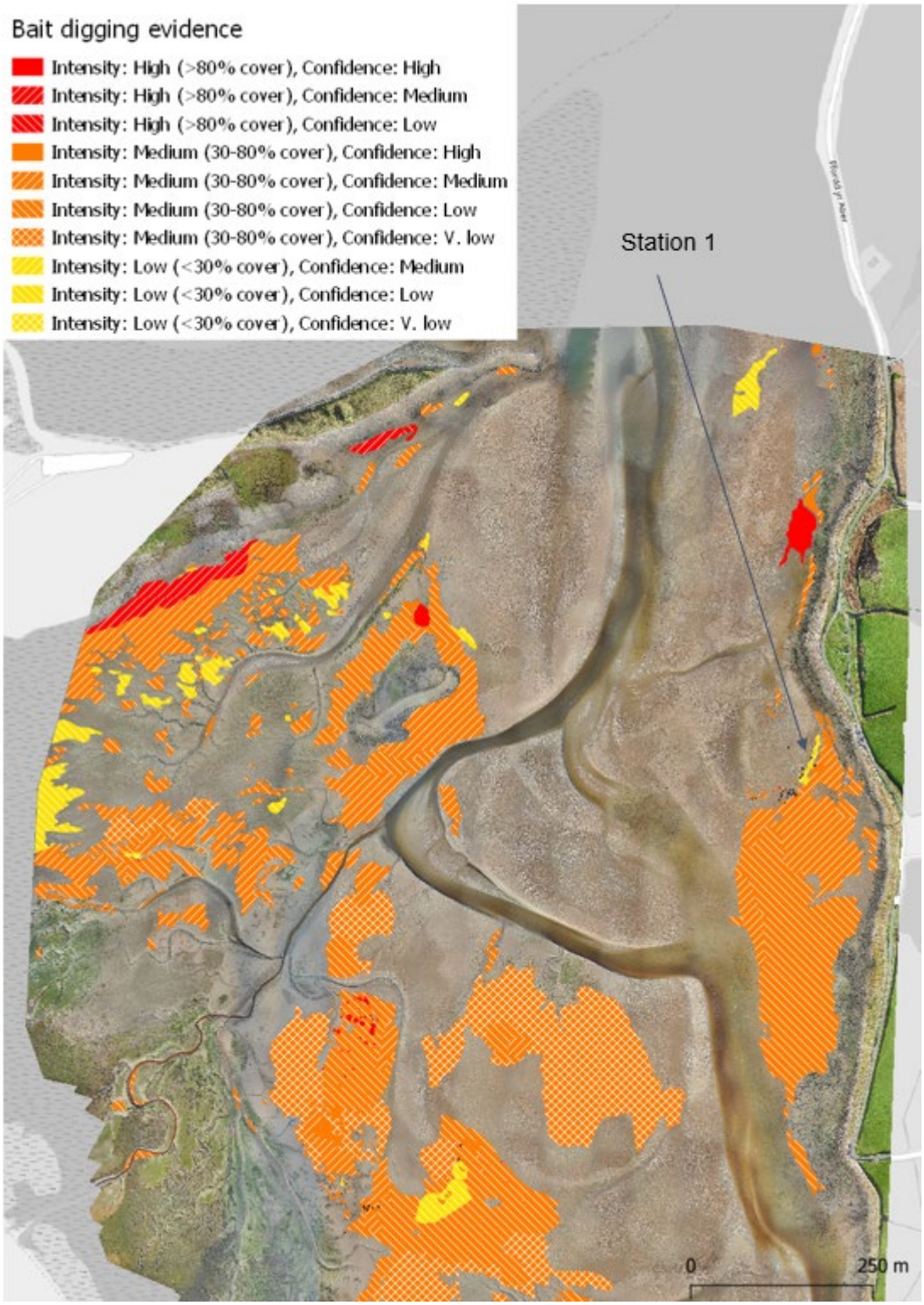


Figure 68 - Bait digging mapped at Y Foryd Bay (North), Caernarfon. Heavy black borders of polygons indicate newly dug areas.

Station

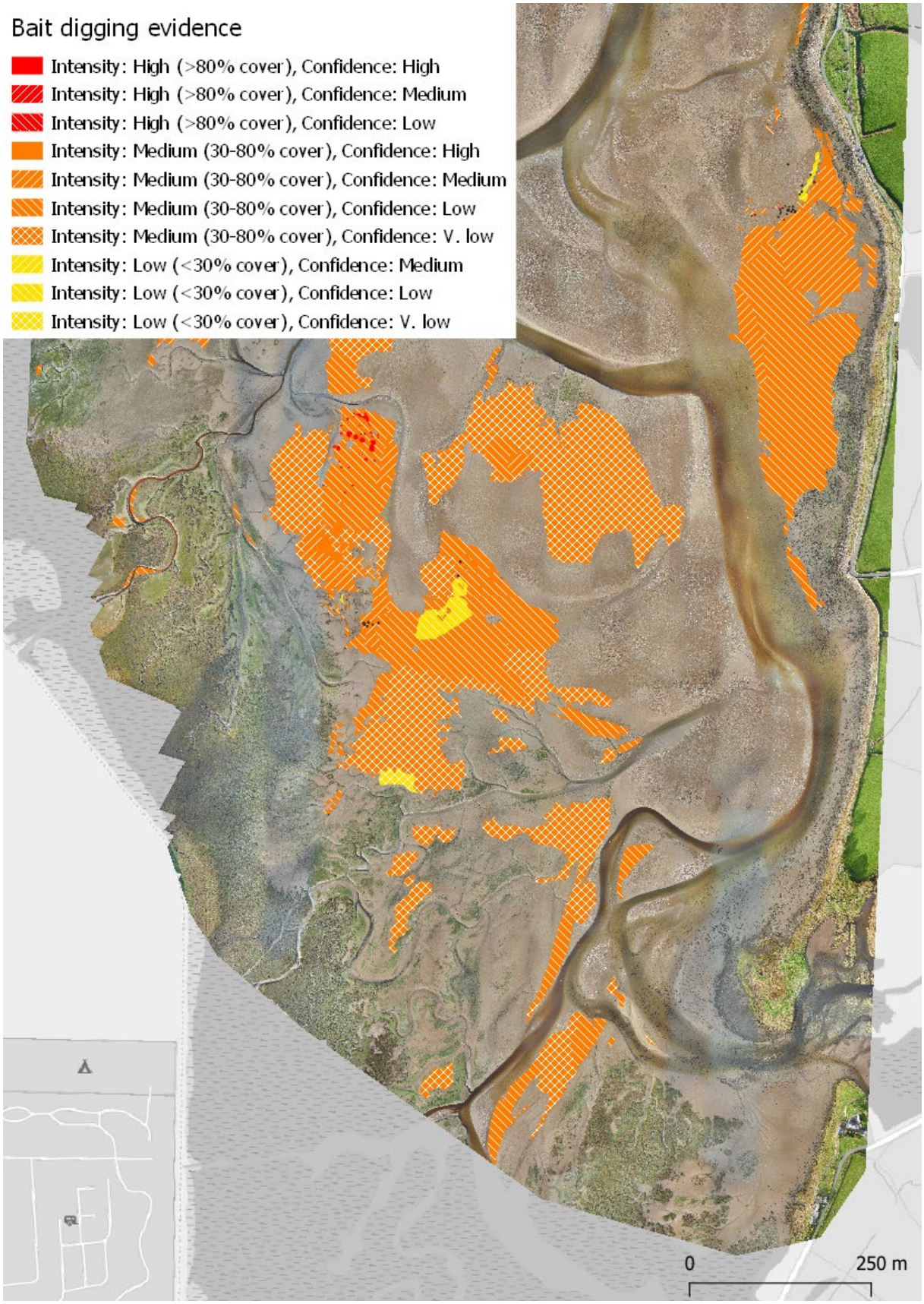


Figure 69 - Bait digging mapped at Y Foryd Bay (South), Caernarfon. Heavy black borders of polygons indicate newly dug areas.

Table 15 - Area in m² of bait digging evidence mapped on Y Foryd Bay, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	3,194	28
Medium	7,471	14
Low	211	No data
Very low	No data	No data
Total	10,876	42

Medium intensity

Confidence	Old (age)	New (age)
High	3,292	14
Medium	80,559	13
Low	117,071	No data
Very low	106,609	No data
Total	307,530	27

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	600	No data
Low	15,769	No data
Very low	1,159	No data
Total	17,528	0

Total dug old and new

Old (age)	New (age)	Combined
335,933	69	336,002

Shore survey - Y Foryd, Menai Strait

General description and accessibility

The shore surveyed was accessed from the minor road that follows the shoreline between Caernarfon and y Foryd which forms the low-level backing to the beach. There is an area of car parking on this road which allows access onto the shore. The shore is backed by cobbles and boulders leading on to sediment which rapidly grades from slightly muddy sand, adjacent to a creek next to the road, to rippled fine sand within 50 m on the main beach. The shore is very sheltered from wave action (<20 km fetch and <3 km fetch from prevailing winds) but the sands are evidently blown by high winds when exposed to the air at low water and by the water flowing on the incoming and outgoing tides and have a rippled and clean appearance.

Figure 70 - Y Foryd taken from the roadside backing the shore. Approximate position of the control holes.

Bait digging distribution

In October 2019 several bait diggers were observed working the sandy sediments with garden forks and bait pumps close to where the control holes were dug. Although the fresh holes they were making were clearly discernible on aerial images there were very few signs of equally prominent holes elsewhere. At ground level there were sparse shallow water-filled depressions in the sediment (approx. < 1 per $10m^2$) but these were indistinct and when examined on foot, their method of creation, whether man-made or natural, is unknown. During the return visit in March 2020 there was no sign of recent bait digging activity.

Habitat

The sandy sediment in the area where the control holes were dug was at the transition between the slightly muddier sands next to the creek that had evidence of *Scrobicularia plana* siphon marks and the more mobile less muddy sand on the main beach that had *Arenicola marina* casts and signs of *Cerastoderma edule* shells (a few live and empty shells).

The level 4 JNCC biotopes LS.LMu.MEst Polychaete/bivalve-dominated mid estuarine mud shores and LS.LSa.MuSa Polychaete/bivalve-dominated muddy sand shores probably best describe the two main biotopes at this location.

Figure 71 - The control holes in y Foryd 27/10/2019. The rippled sand has shallow water-filled depressions that are probably the remains of bait digging holes a few tidal cycles old.

Spatial variability observed

The dug habitats at Y Foryd extended over much of the embayment, although at least two methods were observed for catching different bait species from the different habitats. The more cohesive, slightly muddier sands near the creeks was seen being worked by bait diggers using garden forks, presumably targeting a variety of ragworm (*Alitta virens* and *Hediste* spp.) and lugworm *Arenicola marina*. Smaller holes were also being dug for lugworm in the sandier sediment using garden forks and bait pumps. Where only bait pumps were used these were difficult to see on aerial photography. Ground truthing can help establish that features identified on the aerial photography are caused by bait pumps, but unless the whole site is mapped on foot, any areas identified as potentially impacted will still be recorded as having low confidence.

Persistence of bait digging

Of the two ‘types’ of sediment in the area that the control holes were dug, only the more cohesive muddier sediment seems to retain its three-dimensional structure for more than a few tidal cycles. There were the remains of water-filled depressions seen during both visits to this site, probably from previous digging in this area, but only indistinct depressions in the more mobile sediment. When re-visited in March 2020, 135 days after the first visit, there were no reliable signs that any of the features of the control holes had persisted this long and the sediment surface at the GPS coordinates comprised flat rippled sand.

Figure 72 - The approximate location in Y Foryd where the test holes were dug. The rippled surface shows no obvious signs of the previous disturbance. There are shallow water retaining depression over the whole area as seen during the previous visit. The sand rippling is less pronounced than the previous visit 135 days ago.

Issues encountered

The main limitation for aerial surveys at this site is the proximity of Caernarfon Airport. The initial drone surveys were conducted just before new legislation was introduced which allowed the use of the drone with local verbal permission from the airport. An exclusion zone now exists that is embedded into the flight control software that many drones use which prevents them taking off in the vicinity of an airfield or other restricted categories of controlled airspace. This software ‘lock’ can theoretically be removed, although the process for unlocking has so far not been achieved despite contacting the drone manufacturers.

3.8 Gann Flats, Pembrokeshire

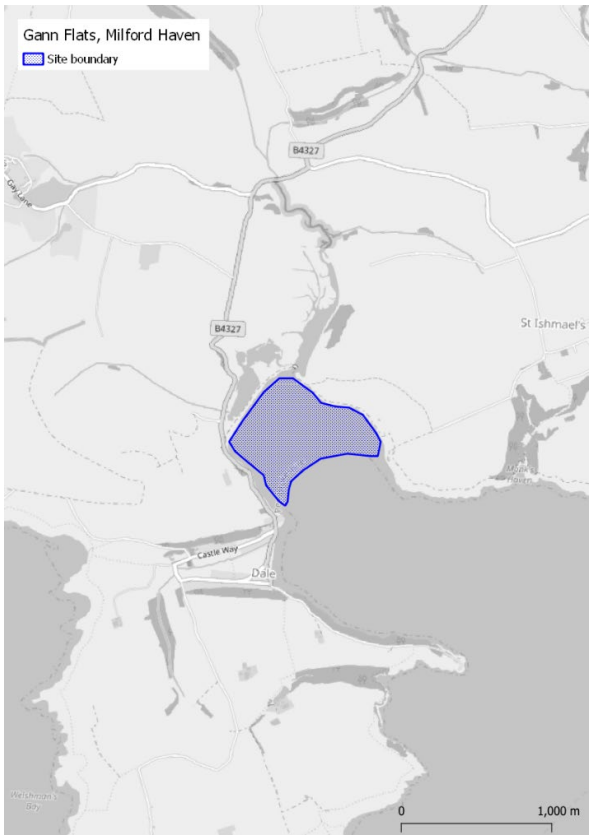


Figure 73 - Survey area - Gann Flats, Pembrokeshire

Table 16 - Gann Flats visit summary

Category	**Information about site surveyed**
Date(s) of flight	28/11/2019
Time(s) of flight	12:20-12:46
Local LW time	13:17 (0.9m) Milford Haven
Field report	20191110 field report Gann Sandy Haven Angle bait.docx
Tiled image file	Gann_20191128.tif
Control stations and habitat(s) observed	**Station 1** SM8123806700 Soft muddy gravel (mostly fine sand rather than mud) and shell flooded with water flowing over the surface. Some *Fucus serratus* on pebbles. *Alitta virens* and various polychaetes in the sediment. LS.LMx Littoral mixed sediment
Shore exposure	Very Sheltered
Area of site	42 ha

Category	Information about site surveyed
Bait diggers observed	Three bait diggers observed – two in voluntary “No dig area”. All using forks. No back filling observed.
Target species	King ragworm (*Alitta virens*)
Date of follow up visit	14/03/2020 (107 days)

Mapping Gann Flats

A total of 264 m² of new and c.14 ha of old evidence of bait digging was mapped at Gann Flats. Overall this covered about a third of the site.

Approximately three quarters of the mapped area (10.4 ha) was regarded as very low confidence, where there was only faint circular patterning in the sediment. The boundaries of these areas were also hard to determine. It was not possible to be more certain regarding the origin of the patterning from analysing the aerial imagery alone, and, due to the low confidence assigned to these areas, it is possible that the total area mapped as affected by bait digging is overstated. However, the visit by the site surveyor documented (in sections 2.8.1.2 – 2.8.1.5 below) that much of the site (especially the central area where the trial holes were dug) was indeed affected by historic bait digging, with remains of depressions and piles of gravel common across the site and evidence of new holes within some areas marked as ‘low / very low confidence’.

Evidence of continual and longstanding digging throughout the site also comes from Morrell (2007), who produced a map showing worm holes over multiple seasons in 2007 and 2008 (26,615 holes in total), the report noting Gann Flats to be the most exploited site within Milford Haven. Photographs in Evans *et al.,* (2015) also show 10+ people digging on the shore and evidence from NRW activity monitoring from 2015 illustrates that large areas of the shore are regularly dug by both recreational and commercial diggers.

The map of holes produced by Morrell (2007) (Figure 74) correlates in terms of total extent with the map derived from the aerial imagery in this contract (Figure 75). However, there are significant areas where no current bait digging evidence was seen on the aerial imagery collected as part of this project. This may be attributed to the stream running over the beach obscuring some evidence, potentially reduced bait digging activity in winter months or winter storms flattening bait digging evidence.

A more focussed ground-truthing, which compared any visible evidence on the ground with what was visible on imagery, would provide a useful follow up to this exercise, with the Gann being a suitable location to test this methodology.

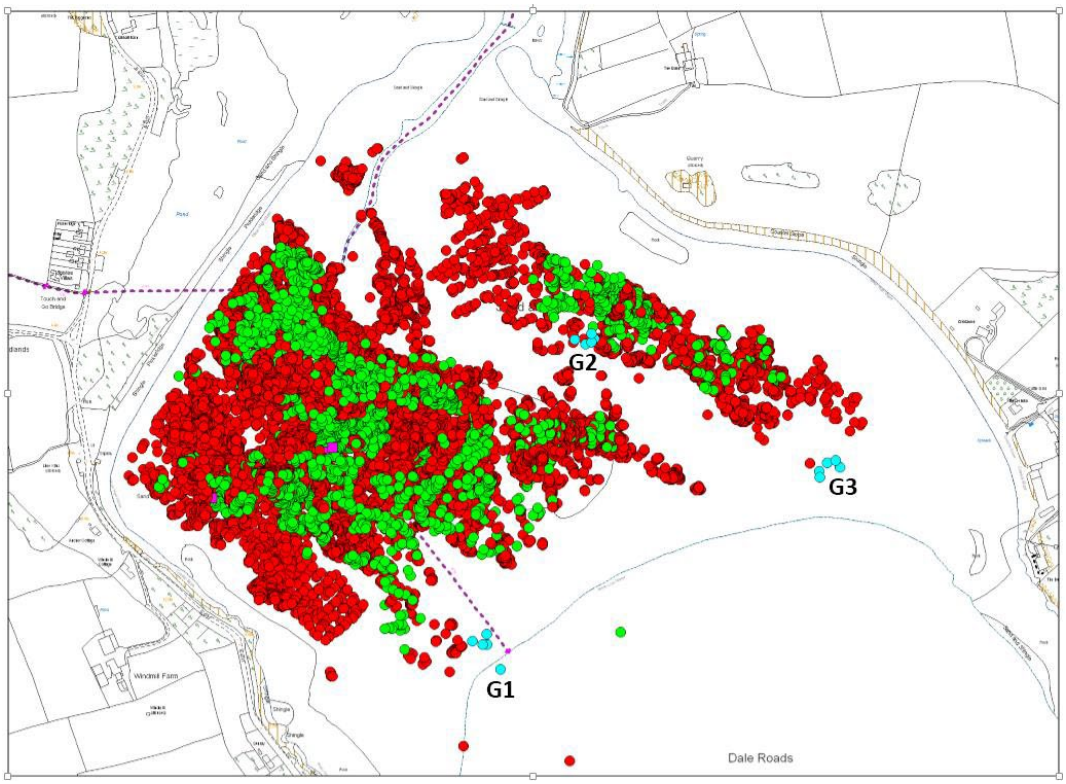


Figure 74 - Morell (2007) GPS locations of dug 'Wormholes' indicating the spatial extent of digging effort over four seasons at the Gann in 2007 and 2008.

Table 17 - Area in m² of bait digging evidence mapped on Gann Flats, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	**Old (age)**	**New (age)**
High	41	143
Medium	4	3
Low	10	No data
Very low	898	No data
Total	954	146

Medium intensity

Confidence	**Old (age)**	**New (age)**
High	6,108	118
Medium	16,236	No data
Low	11,448	No data
Very low	61,277	No data
Total	95,069	118

Low intensity

Confidence	Old (age)	New (age)
High	77	No data
Medium	550	No data
Low	2,897	No data
Very low	41,325	No data
Total	44,849	0

Total dug old and new

Old (age)	New (age)	Combined
140,872	264	141,136

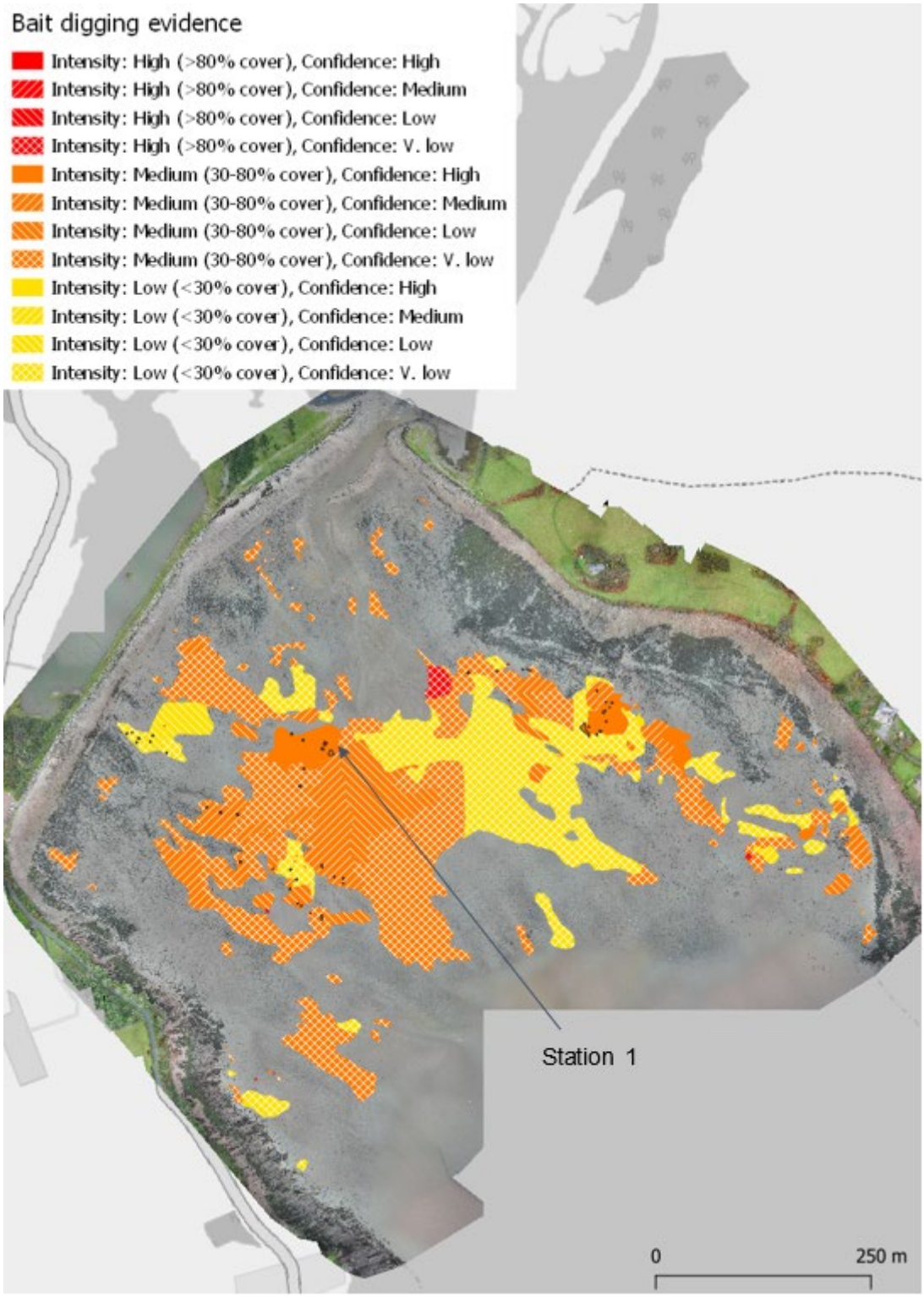


Figure 75 - Bait digging - Gann Flats. Heavy black borders of polygons indicate newly dug areas.

Shore survey – Gann Flats

General description and accessibility

The Gann Flats is a sediment shore located on the north shore of Milford Haven at the head of Dale Roads. It is bounded to the north by the man-made Pickleridge walkway behind which is the Pickleridge Lagoon. The shore is easily accessible by the B4321 which has a car parking area adjacent to the Pickleridge.

The Pickleridge walkway is reinforced by rip-rap leading to the upper shore which comprises fucoid-covered boulders on sediment. The boulders are particularly common on the east and west side of the bay. Progressing down the shore the boulders become scarcer leading to sediment flats with widely scattered fucoid covered boulders and cobbles in the middle and lower shore. A stream of lowered salinity water runs down the shore from the river Gann and fans out over the shore. The route and extent of the water flow from the river Gann varies throughout the year, as does the volume of water (Dr Steven Morrell pers. comm.). The shore faces south-east and is sheltered from wave action (<4 km fetch and totally sheltered from prevailing winds), and the shore experiences only weak (<1 kn) tidal flow.

Figure 76 - The Gann Flat from the Pickleridge. Note bait diggers in the distance on the east side of the shore.

Bait digging distribution

On the first visit to this site on 28th November 2019 there was little evidence of bait digging in the upper middle-shore but extensive bait digging had taken place over the entire lower middle shore and upper part of the lower shore in the middle of the bay. The bait digging exclusion areas to the east and west side were not examined although bait diggers were observed in these areas during both the November 2019

and the March 2020 visits. Whether or not the holes were recently dug was impossible to determine due to the river Gann running right over the middle of the beach. Despite this, evidence of bait digging was obvious due to the many depressions in the sediment surface and piles of gravel brought to the sediment surface by digging. It was estimated that the contiguous depressions occurred at an approximate abundance of >1 per m^2. The depressions were oblong and approximately 0.5 m across and 3 - 10 cm deep and water-filled. It was exceedingly difficult to walk over the sediment due to its soft nature where diggings had occurred.

Figure 77 - Bait dug area in the lower middle shore of the Gann Flats covered in water flowing down the shore at the time of the survey.

Habitat

The sediment at the location of the control holes was fine sand and gravel with the RPD layer almost immediately below the sediment surface. Fauna observed while digging included *Alitta virens* and various smaller polychaetes. This corresponds to the JNCC level 3 biotope *LS.LMx Littoral mixed sediment*. The disturbed nature of the habitat, due to bait digging has not allowed the natural community to develop and so it is not possible to go further up the biotope hierarchy than level 3.

Spatial variability observed

The control holes were confined to the areas that did not fall within the voluntary no digging zones of the Gann Flats (Figure 78) and the whole of the middle to lower shore area seemed to be affected by bait digging. A more accurate picture of spatial variability was not possible due to the high volume of water flooding over the shore from the river Gann caused by heavy winter rainfall.

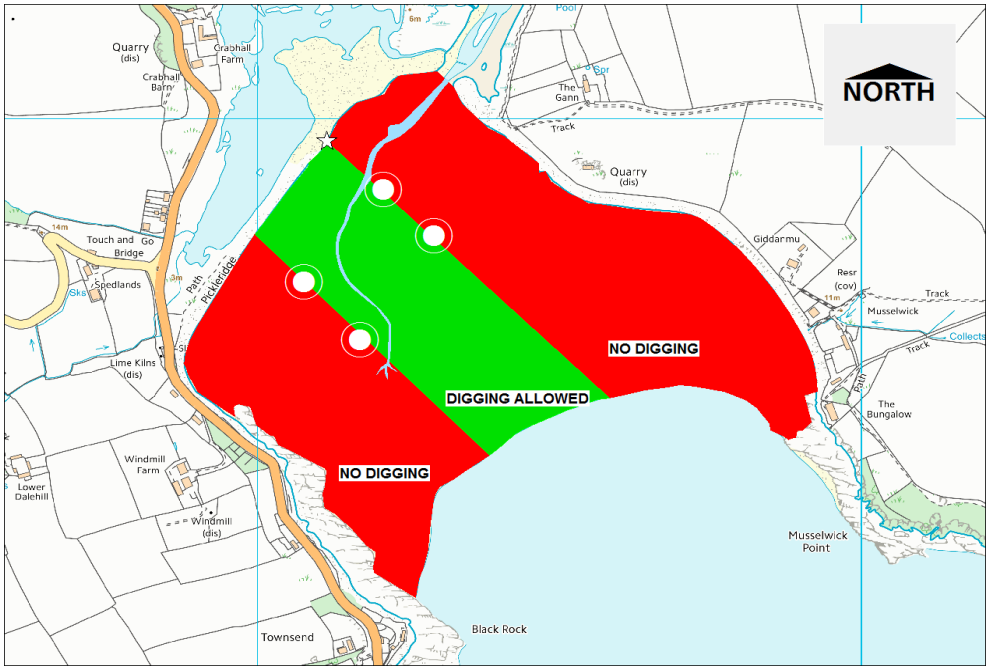


Figure 78 - Voluntary "No Bait Digging" areas on the Gann Flats

Persistence of bait digging

Digging of holes for bait creates piles of sediment and when left, especially not backfilled, the finer particles wash back into the holes leaving coarser sediments such as gravel on the surface. The result has been an extensive patchwork of firm sediment with very soft almost liquid sediments filling old holes. The trial holes dug at the Gann were not easy to re-locate after 107 days. However, previous work suggests that the Gann Flats is worked intensively by bait diggers throughout the year, the sediments never appear to recover.

Figure 79 - Close view of one of control holes, 28/11/2019.

Figure 80 - Picture taken in position of control hole 2, 14/03/2020. Visual evidence of previous holes is not immediately obvious.

Figure 81 - Soft rippled sandy area surrounded by coarse sediment in place of the Gann Flats hole 1 over 3 months later.

Issues encountered

The amount of water from the river Gann running on to the centre of the Gann Flats area of the shore made both digging the control holes and assessing the extent of bait digging difficult at the time of survey.

3.9 Sandy Haven, Milford Haven

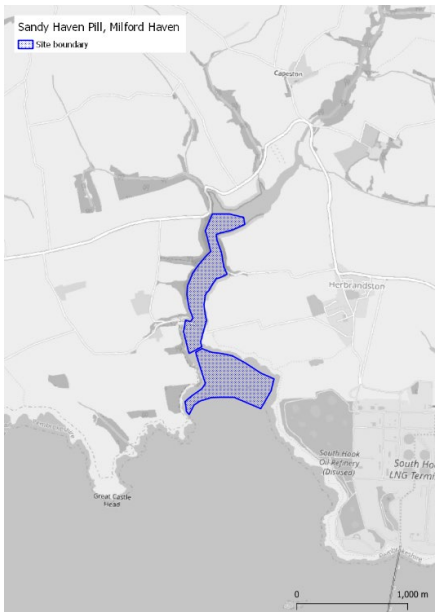


Figure 82 - Survey area - Sandy Haven, Milford Haven

Table 18 - Sandy Haven visit summary

Category	**Information about site surveyed**
Date(s) of flight	28/11/2019
Time(s) of flight	13:39-14:15
Local LW time	13:20 0.9 m (Milford Haven)
Field report	20191110 field report Gann Sandy Haven Angle bait.docx
Tiled image file	SandyHaven_20191128.tif
Control stations and habitat(s) observed	**Station 1** - SM8575708451 Muddy sand (mostly fine sand) with shell and twigs. Many *Peregrina ulvae* and *Hediste diversicolor* burrows visible on the surface and also patches of Ulva. *Hediste* plus other small polychaetes numerous in the sediment. Hard coarse material present at approximately 30 cm depth. LS.LMx.GvMu.HedMx *Hediste diversicolor* in littoral gravelly muddy sand and gravelly sandy mud.
Shore exposure	Extremely Sheltered in Pill

Category	Information about site surveyed
	Sheltered on beach
Area of site	22 ha (Pill) and 24 ha (beach)
Bait diggers observed	3 bait diggers (28/11/2019) observed in Pill 2 bait diggers (14/03/2020) observed in Pill
Target species	Ragworm (Hediste diversicolor), Lugworm
Date of follow up visit	14/03/2020 (107 days later)

Mapping Sandy Haven

A total of 325 m² of new and 3,424 m² of old evidence of bait digging was mapped at Sandy Haven. Overall this covered less than a tenth of the site.

All evidence of bait digging mapped on Sandy Haven occurred north of the plank bridge, where it was scattered between the plank bridge and the small inlet leading up to the Aenon Baptist Chapel (off image to NW Figure 84)

Approximately a tenth of all evidence mapped was new. 261 m² was clearly new bait digging, but the holes were much smaller than occurred on other sites, averaging about 50 cm in maximum diameter, excluding the associated spoil heaps. Small areas of the new evidence mapped were uncertain, being potentially natural or not having the appearance of new evidence at other sites.

Table 19 - Area in m² of bait digging evidence mapped on Sandy Haven, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	4	63
Medium	34	No data
Low	58	12
Total	97	75

Medium intensity

Confidence	Old (age)	New (age)
High	146	175
Medium	570	No data
Low	1,194	No data
Total	1,910	175

Low intensity

Confidence	Old (age)	New (age)
High	No data	74
Medium	No data	No data
Low	1,417	No data
Total	1,417	74

Total dug old and new

Old (age)	New (age)	Combined
3,424	325	3,749

Figure 83 - Bait digging - Sandy Haven (South). Heavy black borders of polygons indicate newly dug areas.

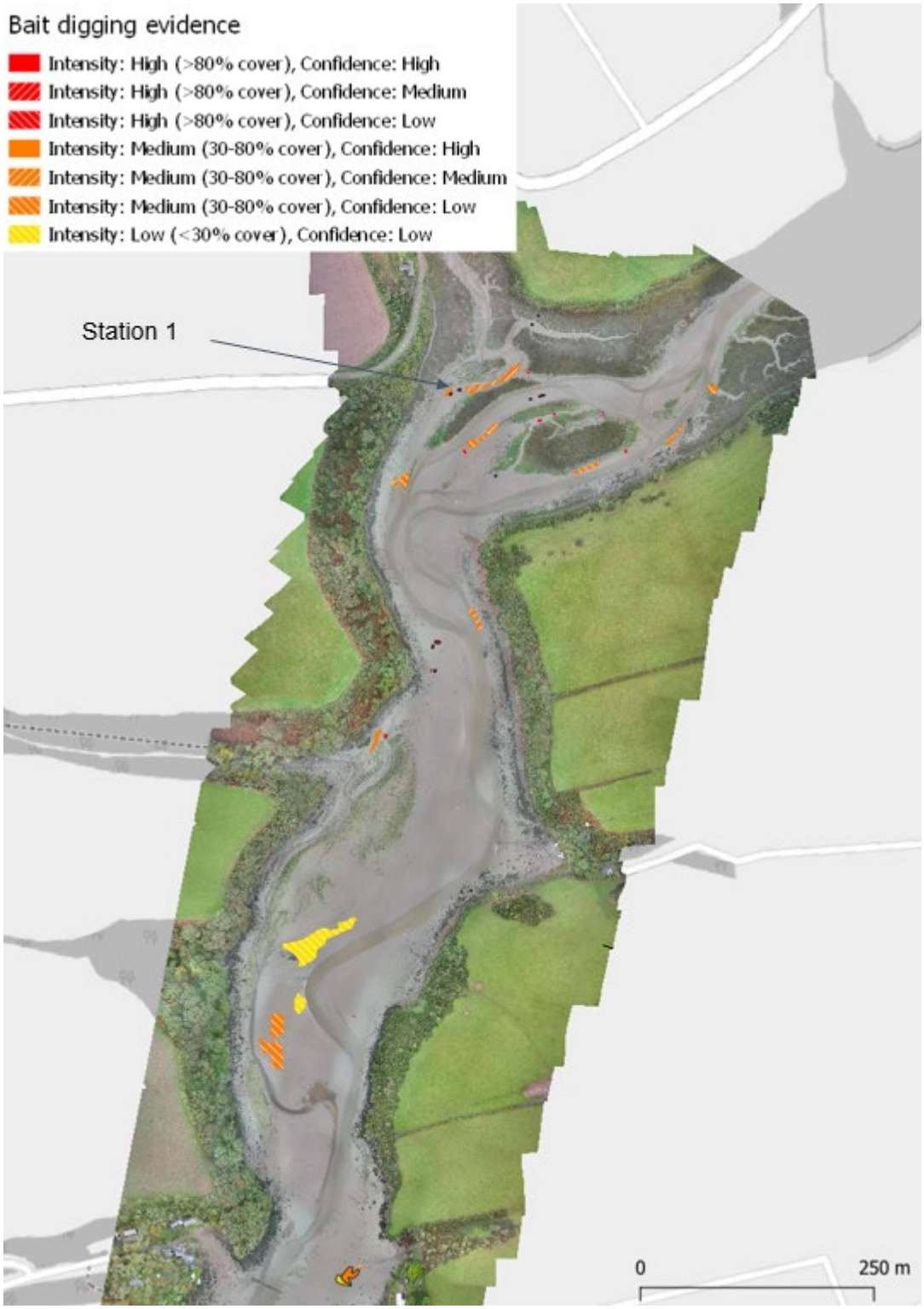


Figure 84 - Bait digging - Sandy Haven (North). Heavy black borders of polygons indicate newly dug areas.

Shore survey – Sandy Haven

General description and accessibility

Sandy Haven is an inlet on the north shore of Milford Haven, approximately 700 m wide at the entrance. The seaward end is marked by a sandy beach and the inlet extends north approximately 2.5 km inland to Rickeston Mill, narrowing *en route* and sediments grade from sand to mud and saltmarshes dominate the banks of the creeks.

Sandy Haven is easily accessible from the road by Aenon Baptist Chapel and also via Herbranston. The survey area was in the upper reaches of Sandy Haven near to Aenon Baptist Chapel at a site where bait diggers were observed working at the time of the initial survey and evidence of previous bait digging was present. Here the sediment consisted of fine and muddy sand bounded by saltmarsh. The shore here is very sheltered from wave action (<1km fetch and <200 m from prevailing winds). Tidal flows will be rapid (estimated at 2 knots) during the flood and ebb.

Figure 85 - Evidence of bait digging in the upper reaches of Sandy Haven where test holes were dug.

Bait digging distribution

The area in the vicinity of Aenon Baptist Chapel was found to have the most noticeable evidence of bait digging. The open beach area to the south of the site was also flown (as shown in Figure 83) but no bait digging evidence was observed from these aerial images. The bait digging observed on the mud flats in the upper reaches of Sandy Haven was widespread. A total of 3 bait dug areas were observed at the time of the visit on November 28th 2019 and two more were observed on March 14th 2020 and active bait diggers were observed. A good example of the intensity of bait

digging is shown in Figure 85 where there were five holes along the banks of the main creek over a distance of approximately 15 m, with each hole being approximately 0.5 m in diameter and 30 cm deep. How long the observed holes had been in existence is unknown. Bait digging in this area is likely to be mainly for Ragworm (*Hediste diversicolor),* although digging for lugworm is also likely.

Habitat

The sediment at the location of the control holes was muddy sand (mostly fine sand) with shell and twigs with an RPD layer almost immediately below the sediment surface. Many *Peregrina ulvae* and *Hediste diversicolor* burrows were visible on the surface and also patches of *Ulva* sp(p). *Hediste* plus other small (unidentified) polychaetes numerous in the sediment and hard coarse material present at approximately 30 cm depth.

This corresponds to the JNCC level 4 biotope *LS.LMx.GvMu.HedMx Hediste diversicolor* in littoral gravelly muddy sand and gravelly sandy mud.

Trampling and damage to the sediment communities is a problem with sampling in this area because they are vulnerable to disturbance.

Spatial variability observed

The upper part of Sandy Haven by Sandy Hill is approximately 300 m wide and is comprised of raised mudflats bounded by saltmarsh and intersected by creeks, with the main channel being Sandy Haven Pill. Freshwater flowed down the creeks from the streams at Sandy Hill and Rickeston Mill. The sediment targeted for bait digging and where control holes were dug was uniform in nature.

Persistence of bait digging

Two control holes were dug on 28th November 2019. When the area was revisited on 14th March 2020 (107 days later) the holes were still clearly visible and had been slightly enlarged by scour over this time. The base of the holes contained shell material. Adjacent to the experimental holes, the holes dug by a bait digger had caused some erosion of the creek banks (see Figure 88). The sheltered, fine sediments in this region of Sandy Haven are fragile and vulnerable to disturbance.

Figure 86 - Control holes dug in Sandy Haven on 28th November 2019

Figure 87 - Control holes still present on 14th March 2020 (107 days) and enlarged by scour

Figure 88 - Erosion of creek banks caused by bait digging.

Issues encountered

There were no significant issues with surveying this site. Spring low water is in the middle of the day so light levels were generally good.

3.10 Gelliswick Bay, Milford Haven

Figure 89 - Survey area - Gelliswick Bay, Milford Haven

Table 20 - Gelliswick Bay visit summary

Category	**Information about site surveyed**
Date(s) of flight	29/11/2019
Time(s) of flight	1430-1530
Local LW time	14:00 1.1 m (Milford Haven)
Field report	20191110 field report Pembrokeshire.docx
Tiled image file	Gelliswick_20191129.tif
Control stations and habitat(s) observed	Station 1 SM 88575 05486

Category	Information about site surveyed
	LS.LMx Littoral mixed sediment
Shore exposure	Sheltered
Area of site	56 ha
Bait diggers observed	3 (on east side of the beach)
Target species	Lugworm - *Arenicola marina* (east and west sides) and King Ragworm - *Alitta virens* (west side only)
Date of follow up visit	14/03/2020 (107 days)

Mapping Gelliswick

A total of 23 m² of new and 41 m² of old evidence of bait digging was mapped at Gelliswick Bay. Overall this covered less than 1% of the site.

All the evidence of bait digging at Gelliswick Bay was on the lower shore. Confidence in the interpretation was high, with about a third of the area mapped being new bait digging. This may suggest that evidence is washed away by tidal action at this site.

Table 21 - Area in m² of bait digging evidence mapped on Gelliswick Bay, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	No data	23
Medium	No data	No data
Low	No data	No data
Total	0	23

Medium intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	41	No data
Low	No data	No data
Total	41	0

Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	No data	No data
Low	No data	No data
Total	0	0

Total dug old and new

Old (age)	New (age)	Combined
41	23	64

Figure 90 - Bait digging - Gelliswick Bay. Heavy black borders of polygons indicate newly dug areas.

Shore survey – Gelliswick Bay

General description and accessibility

Gelliswick Bay (Figure 89) is located on the north shore of Milford Haven. It is bounded to the west by the Puma Energy (formerly Murco), petroleum storage and distribution terminal jetty and by Hakin Fort to the east. The hinterland is developed with a seawall bounding the back of the beach, behind which is a road and the Pembrokeshire Yacht Club.

A concrete boat slip bisects the bay, running from the road to the bottom of the middle shore. A storm water culvert is located on the west side of the beach from which freshwater issues onto the shore and runs down the beach. The beach itself consists of shingle in the upper shore which grades to sand dominated sediment in the lower shore. Small boulders and cobbles are scattered over the beach, particularly on the west side.

Gelliswick Bay is a sheltered shore. Although it is open to the south west, the bay is afforded shelter by the narrowed entrance to Milford Haven (the fetch to St Anne's head is 14 km) and the presence of the petroleum industry jetties to the west. The lower shore will experience some of the east / west tidal flow of Milford Haven, accelerating the current here to an estimated 2 to 3 kn during spring tides. Further into the bay, these currents will decrease to a weak tidal flow (<1 kn). There is a gradient of exposure along the beach which is more sheltered on the west side than the east.

Figure 91 - Gelliswick Bay from road (stitched panorama), 27/12/2019. Arrow shows location of bait diggers.

Bait digging distribution

The aerial photographs taken on 29th November 2019 showed an area of possible bait digging activity on the west side of the bay towards the lower shore. This area was targeted on December 27th 2019 and evidence of bait digging in the form of piles of gravel around disturbed sediment was noted (see Figure 92) and control holes were then dug here. The estimated intensity of bait digging was low at 1 hole per 33 m^2. While digging the control holes, a small group of three bait diggers were preparing to work on the east side of the beach in sandier sediments, though evidence of this activity or past activity in this location was not picked up by the aerial

imagery. Bait digging will likely be confined to the lower shore as the sediments higher up are too stony for effective digging.

Figure 92 - Bait dug area in the shore on the west side of Gelliswick Bay.

Habitat

The sediment at the location of the control holes was fine muddy sand with some surface water and sand ripples on the surface. The RPD layer was approximately 3 cm deep. The sand mason worm, *Lanice conchilega*, was common with tubes visible on the sediment surface. Few polychaetes or other fauna were observed when digging. This corresponds to the JNCC level 3 biotope *LS.LMx Littoral mixed sediment*. Without further analysis it is not possible to go further up the biotope hierarchy than level 3.

Spatial variability observed

The shore survey was confined to the west side of the Gelliswick Bay where NRW had identified previous bait digging activity. Local bait diggers operating on the east side of the bay were digging for lugworm *Arenicola marina* and indicated to surveyors that digging also occurred on the west side where king rag *Alitta virens*, a species prized by bait diggers, could occasionally be found.

Persistence of bait digging

On a return visit to Gelliswick Bay on March 13th 2020, the holes had largely filled in, although the location of one of the trial holes could be identified by a ring of gravelly substrata in the holes previous location. The trial holes infilled with firm sediment (unlike those encountered at the Gann Flats and Angle Bay). It was noted that there had been a deposit of sand in this part of the beach since the first visit as some of the rocks visible in December 2019 were buried. The lack of persistent evidence at

Gelliswick may mean that the area of shore that is subject to bait digging is under represented by this survey.

Figure 93 - Control hole 1 being dug with control hole 2 in background, 28/11/2019.

Figure 94 - Picture taken in position of control hole 1, 14/03/2020. The ring of gravel may have been the result of digging hole 1 on 27/12/2019.

Issues encountered

The stony nature of the sediment made digging on the west side of the beach difficult, but the substrata is suitable for the king rag worm *Alitta virens* which is prized by bait diggers which would attract them to this area.

3.11 Angle Bay

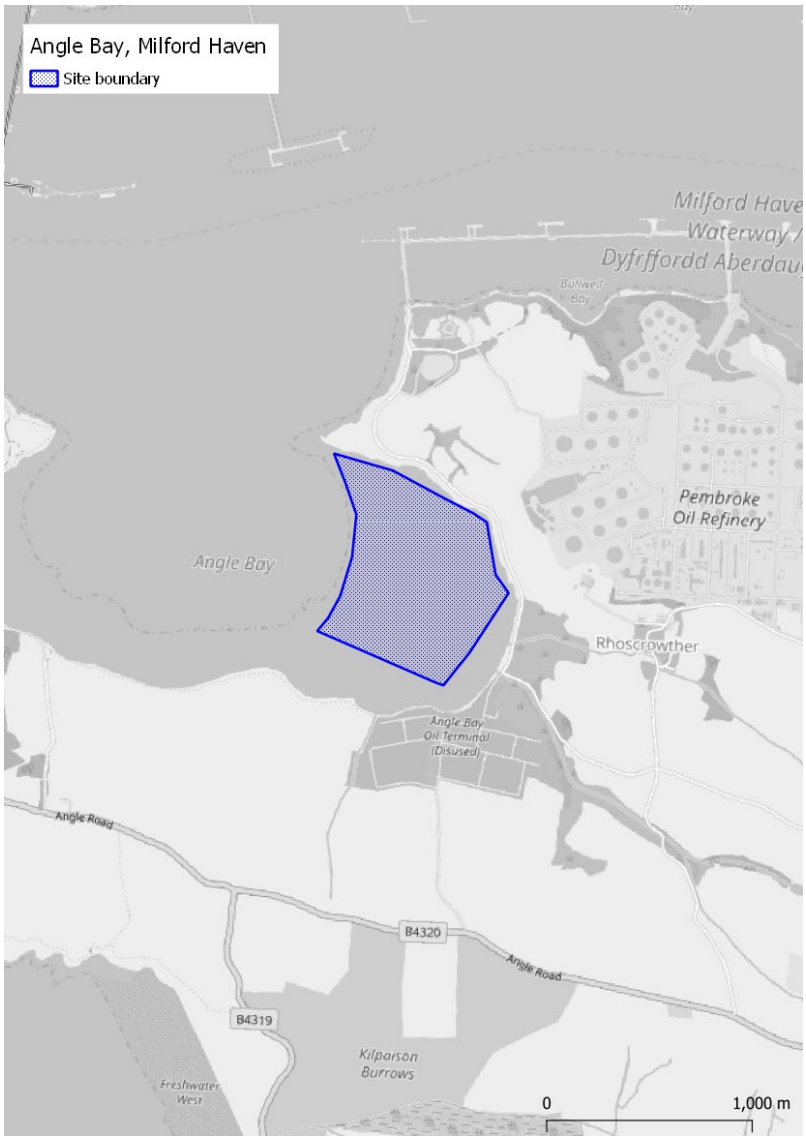


Figure 95 - Survey area - Angle Bay

Table 22 - Angle Bay visit summary

Category	Information about site surveyed
Date(s) of flight	29/11/2019
Time(s) of flight	13:12-13:34 13:38-13:47
Local LW time	14:00 1.1 m (Milford Haven)
Field report	20191110 field report Gann Sandy Haven Angle bait.docx
Tiled image file	Angle_20191129.tif

Category	Information about site surveyed
Control stations and habitat(s) observed	**Station1** - SM8946602827 Muddy sand (mostly fine sand) with Zostera notlei, Peregrina ulvae, Littorina saxatilis, Cerastoderma edule. Many polychaetes including *Hediste diversicolor* were present in the sediments. Hard material present at approximately 30 cm depth. LS.LMp.LSgr.Znol - *Zostera notlei* beds in littoral muddy sand. **Station 2** - SM8912202979 Rippled medium fine sand covered with standing water and with *Cerastoderma edule*, *Littorina littorea* and the occasional *Ostrea edulis* LS.LSa.MuSa.CerPo - Cerastoderma edule and polychaetes in littoral muddy sand.
Shore exposure	Very Sheltered
Area of site	62 ha
Bait diggers observed	0 – no backfilling observed
Target species	Lugworm (Arenicola marina) and Ragworm (Hediste diversicola)
Date of follow up visit	15/03/2020 (107 days)

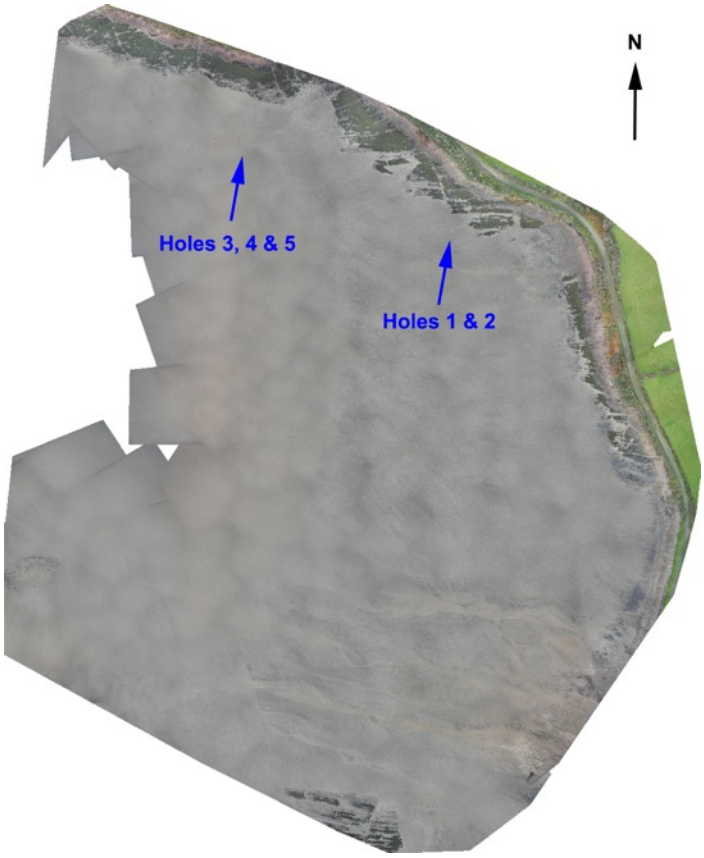


Figure 96 - Orthomosaic preview of the area of Angle Bay, Pembrokeshire. The approximate location of the control holes is indicated by the arrows (Station 1 = holes 1 & 2, Station 2 = holes 3 & 4)

Mapping Angle Bay

A total of 243 m² of new and c.29 ha of old evidence of bait digging was mapped at Angle Bay. Overall this covered about a third of the site.

Seaward aerial imagery cover of Angle Bay was incomplete. Based on the extent of evidence of bait digging it is unlikely that this was a significant issue, as the evidence of bait digging stopped well before the aerial coverage.

The extent of old bait digging evidence at Angle Bay was hard to define over some very large areas. This affected c.4 ha of low intensity and c.23 ha of medium intensity evidence. These areas were all mapped as low confidence, in part owing to the uncertainty of the extent but also due to the indistinct nature of the evidence.

66 m² of the area mapped as low confidence was thought to be potentially natural patterning in the sediment rather than artificial disturbance caused by bait digging. The impact of this on the overall results is minimal. Additional follow up ground truthing would have assisted in clarifying this.

Table 23 - Area in m² of bait digging evidence mapped on Angle Bay, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	**Old (age)**	**New (age)**
High	No data	52
Medium	290	No data
Low	244	No data
Total	534	52

Medium intensity

Confidence	**Old (age)**	**New (age)**
High	No data	192
Medium	9,114	No data
Low	233,734	No data
Total	242,848	192

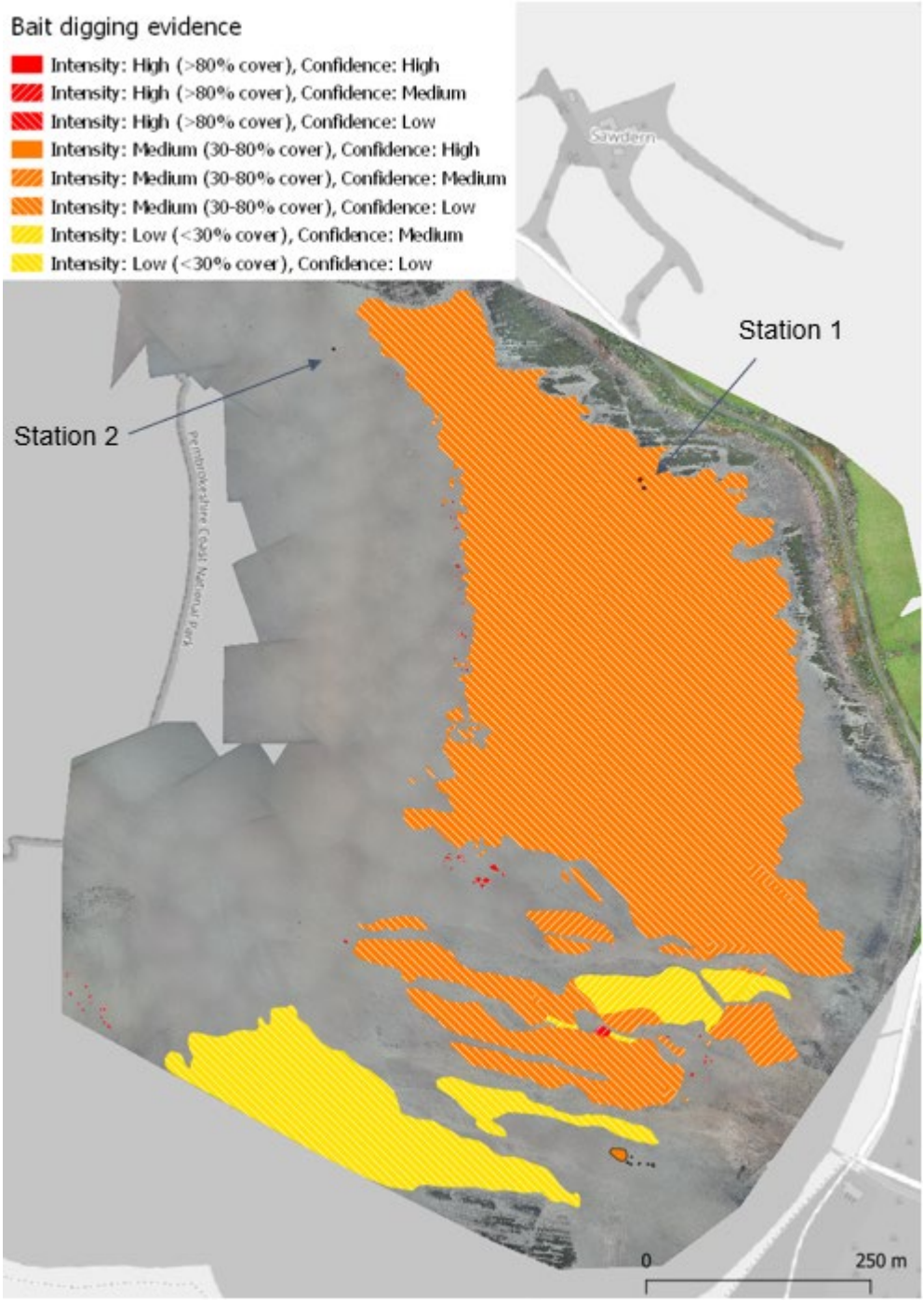
Low intensity

Confidence	Old (age)	New (age)
High	No data	No data
Medium	8,495	No data
Low	42,092	No data
Total	50,587	0

Total dug old and new

Old (age)	New (age)	Combined
293,970	243	294,213

Figure 97 - Bait digging - Angle Bay. Heavy black borders of polygons indicate newly dug areas.



Shore survey – Angle Bay

General description and accessibility

Angle Bay is a large sediment dominated north facing embayment on the south side of Milford Haven, opposite to the petroleum terminals of South Hook LNG and Puma Energy.

The entrance to the bay is marked by the rocky shores of Angle Point to the west and Sawdern Point to the east, with a distance between them of approximately 1.3 km. The majority of the bay area is intertidal with sediments ranging from medium sand to muddy sands and include muddy gravels. The fringes of the bay on the west side are bounded by saltmarsh. This shore is very sheltered from wave action, with a fetch of 8 km to the NW and sheltered from tidal streams (<1 kn).

The east and west sides of Angle Bay can readily be accessed by road but the south side is only readily accessible by foot. The shore survey area highlighted by NRW to examine bait digging was the north east side of the bay where collecting of bait commonly occurs in a bed of *Zostera notlei* (Figure 85).

Figure 98 - The east side of Angle Bay looking west over intertidal *Zostera notlei*.

Bait digging distribution

Only the NE section of Angle Bay was studied. Two areas were chosen for study. The first was in the intertidal bed of *Zostera notlei* and the second in sandy sediments lower down the shore. No bait diggers were observed during the field visits.

Bait digging is extensive within the *Zostera* bed. Where sediments have been dug, the holes become filled with liquified colloidal sediment that cannot support weight

making access to the site difficult and slow. Within the *Zostera* bed, bait digging was at an estimated density of one hole per 2 m^2.

On the lower shore (below the *Zostera notlei*), the sediments were firmer with a coating of rippled sand and little obvious bait digging had taken place (see Figure 99) with only one filled in hole recorded.

Figure 99 - Rippled sand on the sediment surface of the lower shore at Angle Bay

Digging the *Zostera notlei* bed appears at first sight to cause no long-lasting damage or change as the plants will grow back over areas which have been dug. This is masking the damage and change to the sediment structure, where firm sediments are being replaced with soft liquified mud. The duration of this effect and its impact on the naturally occurring sediment communities is unknown.

The effects of the digging on the firm sand communities of the lower shore is unknown but less digging is apparent in this habitat in comparison to within the *Zostera*.

Station 1 – Zostera notlei

The sediment colonised by *Zostera notlei* is firm muddy sand (apart from old bait digging holes which are extremely soft liquified sediment). Standing water covered most of the substrata surface. At a depth of approximately 30 cm the sediment becomes gravelly. The RPD layer here is indistinct starting at 1 to 3 cm in depth, then grading to black at 3 to 5 cm depth.

Conspicuous fauna included *Peregrina ulvae*, *Cerastoderma edule* (mainly small) and various (unidentified) polychaete worms. The biotope corresponds to the JNCC level 5 biotope *LS.LMp.LSgr.Znol - Zostera notlei beds in littoral muddy sand.*

Station 2 – Lower shore firm rippled sand

Lower shore sediments on the east side of Angle Bay comprised of firm medium and fine rippled sand with standing water. At a depth of approximately 30 cm, some clay was encountered.

Conspicuous fauna included *Cerastoderma edule* and *Hediste diversicolor*. Edible periwinkles *Littorina littorea* and a few oysters *Ostrea edulis* were recorded on the sediment surface. The biotope corresponds to the JNCC level 5 biotope *LS.LSa.MuSa.CerPo - Cerastoderma edule and polychaetes in littoral muddy sand*.

Spatial variability observed

The area colonised by *Zostera noltei* was last reported in 2013 (Duggan-Edwards and Brazier, 2015) with an estimated area of 31.95 ha. The area of firm rippled sand was also extensive but has neither been mapped nor measured.

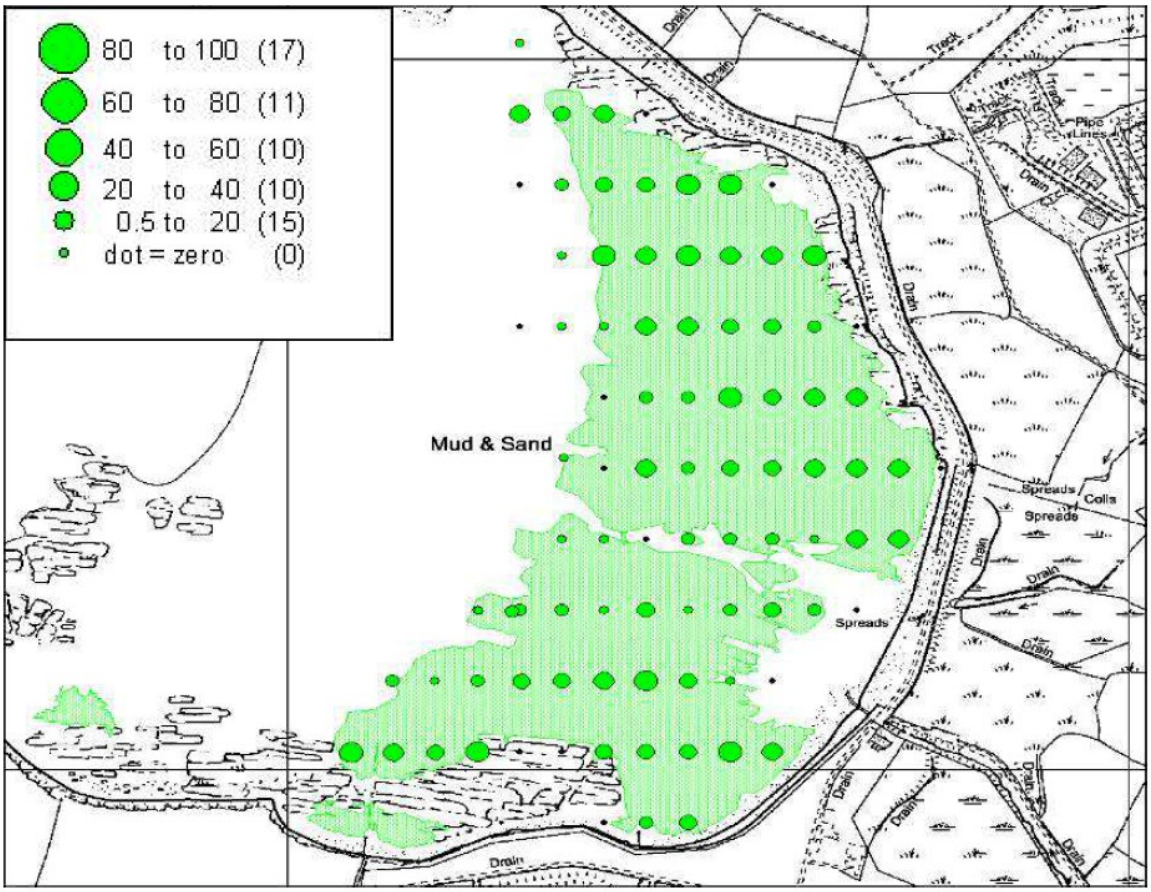


Figure 100 - Area of Angle Bay colonised by *Zostera notlei* as surveyed in 2013 from (Duggan-Edwards and Brazier, 2015)

Persistence of bait digging

Zostera notlei

Two control holes were dug on 29th November 2019. When the area was revisited on 15th March 2020 the locations where the holes were dug were marked by shallow pools over soft rippled, liquid sediment (see Figure 101 and Figure 102). Evidence from holes dug in the past by bait diggers make it probable that the control holes will become recolonised by *Zostera* over time but that the nature of the sediment will remain soft.

Figure 101 - control hole 2 in *Zostera notlei* on November 29th 2019

Figure 102 - vestiges of control hole 2 in *Zostera notlei* on March 15th 2020

Lower shore firm rippled sand

Two large and one small control holes were dug on 29th November 2019 (see example in Figure 103). When the area was revisited on 15th March 2020 the places where these holes had been dug were no longer visible but were still represented by soft liquid sediment in which the weight of a person would sink (see Figure 105.).

Figure 103 - showing control hole 2 in the lower shore firm rippled sand habitat at Angle Bay on 29th November 2019.

Figure 104 - showing surveyor standing next to control hole 2 in the lower shore firm rippled sand habitat at Angle Bay on 15th March 2020.

Figure 105 - showing surveyor standing in the soft sediment of control hole 2 in the lower shore firm rippled sand habitat at Angle Bay on 15th March 2020.

Issues encountered

There were no significant issues with surveying this site. Spring low water is in the middle of the day and light was sufficient to conduct the UAV survey.

3.12 Swansea Bay

Figure 106 – Planned survey area - Swansea Bay

Table 24 – Swansea Bay visit summary

Category	Information about site visited
Date(s) of flight	13/03/2020
Time(s) of flight	14:00-15:30
Local LW time	14:58 (0.5m) Swansea
Field report	None
Tiled image file	Swansea_20200313.tif
Control stations and habitat(s) observed	**Station 1** - SS 62938 91265 Medium to fine rippled sand and shell with surface water between the ripple ridges. The RPD layer approx 7 cm deep. LS.LSa.FiSa.Po Polychaetes in littoral fine sand.

Category	Information about site visited
	Station 2 - SS 62262 90360 Medium to fine rippled sand and shell with little standing water. The RPD layer was approx 15 cm deep. LS.LSa.FiSa.Po Polychaetes in littoral fine sand.
Shore exposure	Moderately Exposed
Area of site	624 ha (note 474 ha flown)
Bait diggers observed	4 bait diggers – one with suction pump – no back filling observed
Target species	Lugworm - Arenicola marina
Date of follow up visit	Not revisited

Mapping Swansea Bay

Table 25 - Area in m² of bait digging evidence mapped on Swansea Bay, broken down by age of evidence, intensity of evidence and confidence in the assessment.

High intensity

Confidence	Old (age)	New (age)
High	No data	18
Medium	247	2
Low	4	No data
Very low	4,281	No data
Total	4,532	20

Medium intensity

Confidence	Old (age)	New (age)
High	1,055	775
Medium	18,248	No data
Low	23,885	No data
Very low	25,089	No data
Total	68,277	775

Low intensity

Confidence	Old (age)	New (age)
Medium	1,973	No data
Low	2,659	No data
Very low	4,612	No data
Total	9,247	0

Total dug old and new

Old (age)	New (age)	Combined
82,056	795	82,851

It was initially intended to fly the whole of the Swansea Bay site, but due to the poor weather conditions experienced during the project, aerial photography coverage for Swansea Bay was incomplete, covering only the southwest three-quarters of the site(Figure 107).

A total of 795 m² of new and c.8 ha of old evidence of bait digging was mapped at Swansea Bay (Table 25). Overall this covered less than 5% of the part of the site with aerial photography.

It is likely that most of the lower confidence evidence of bait digging mapped at Swansea Bay was natural patterns in the sediment. This is especially true on the lower shore, where other features may have produced patterns in the sediment similar in appearance to bait digging. For example, some of the very low confidence evidence mapped occurred around reefs that could have affected patterns of tidal scour in the nearby sediment. Bait diggers are also less likely to walk to the lower shore when there are locations for bait digging closer to access points.

Bait diggers were visible on the aerial photography in two locations (Figure 107). In both instances the holes being dug were smaller than seen on other sites, with an average widest diameter of about 60 cm.

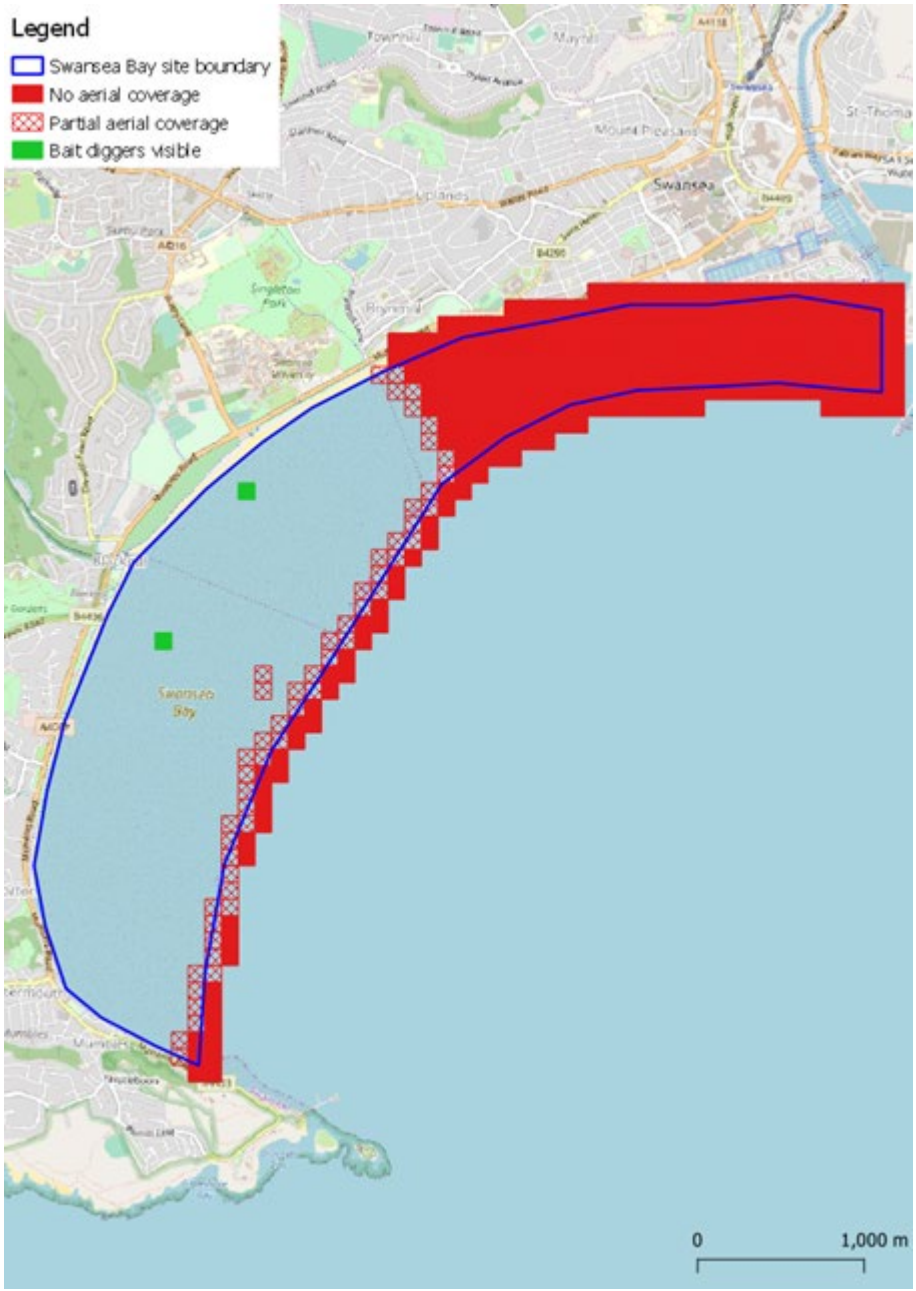


Figure 107 - Approximate location of missing aerial imagery (red) and active bait diggers (green) at Swansea Bay.

Figure 108 - Bait digging South Swansea Bay. Heavy black borders of polygons indicate newly dug areas.

Figure 109 - Bait digging Mid Swansea Bay. Heavy black borders of polygons indicate newly dug areas.

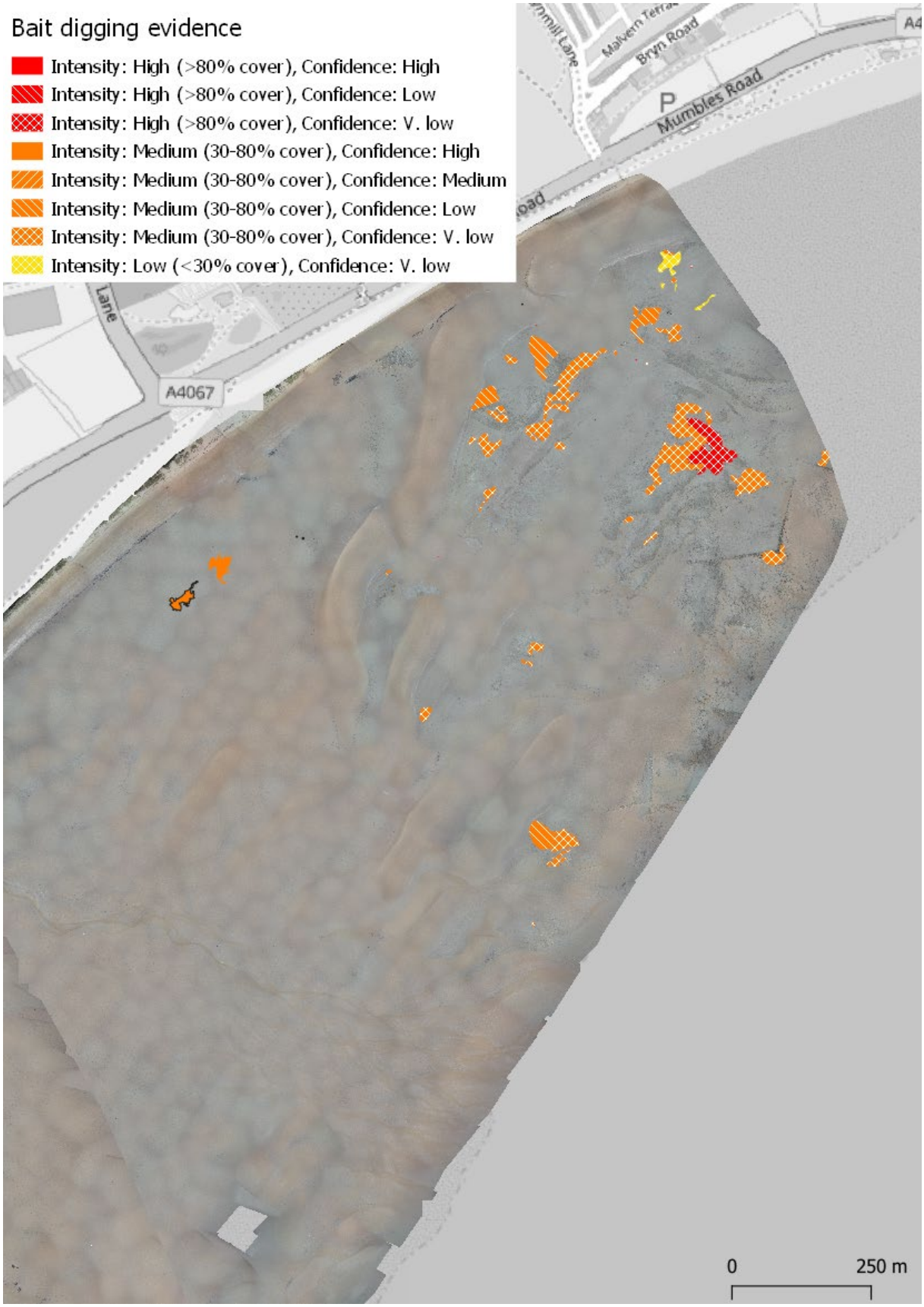


Figure 110 - Bait digging North Swansea Bay. Heavy black borders of polygons indicate newly dug areas.

Shore survey – Swansea Bay

General description and accessibility

The intention was to fly the whole of Swansea Bay but due to time limitations, only the Blackpill area, to the south of the Bay, was surveyed. This area was within a SSSI and was considered to be an area of Swansea Bay where a significant amount of bait digging occurred.

Blackpill is a suburban area of Swansea, at the west end of Swansea Bay. It is approximately 3 miles south west of the city centre. The area is centred on a seafront building on Mumbles road, which once served as a station and power station for the Swansea and Mumbles Railway. Backing the beach is a public walkway and cycle path and the Blackpill stream discharges onto the beach.

Blackpill beach (Figure 911) is moderately exposed to wave action. The western part of Swansea Bay is protected from the west and south west by the Mumbles but is open to the south and east with a fetch of approximately 45 km across the Bristol Channel to North Devon. Tidal flow travels west to east with the flood tide and east to west with the ebb with a back eddy that circulates the bay with currents up to 5.5 kn (Heathershaw and Hammond, 1979).

Figure 111 Blackpill sediment flats, Swansea Bay (with bait diggers) 13/03/20.

Bait digging distribution

Due to the mobile nature of the sandy sediments, holes resulting from bait digging are only likely to only be observable during a single low tide period. A study over a longer time period would be necessary to accurately assess the distribution of bait digging in Swansea Bay.

During the field visit on March 13th 2020, bait collectors were only observed in an area approximately 800 m east of Blackpill. One pair of bait collectors were digging using forks (Figure 92) and had dug in an area estimated to be approximately 30 m^2 and over 20 holes were counted. Some holes had filled in already due to the prevalence of surface water. Another bait collector was working adjacent to the diggers using a bait pump (Figure 113). It was assumed that bait collecting would be concentrated on the middle shore as there was an abundance of *Arenicola* casts easily accessible a short walk from the road. The lower shore was a considerable distance from the road and there were many low lying rocky reefs present which is likely to make digging difficult.

Figure 112 Bait digging to the east of Black Pill 13/03/2200

Figure 113 Bait digger using a suction device east of Black Pill 13/03/20

Habitat

Two locations were studied during the field visit on 13th March 2020. Both were variation on the same biotope; JNCC level 4 biotope *LS.LSa.FiSa.Po Polychaetes in littoral fine sand*.

Station 1

The sediment at this location comprised of medium to fine rippled sand and shell with surface water between the ripple ridges. The RPD layer was approximately 7 cm deep. The only conspicuous fauna noted was the lug worm, *Arenicola marina*. Station 1 is illustrated in Figure 114, Figure 115 and Figure 116 below.

Station 2

The sediment was composed of medium to fine rippled sand and shell with little standing water. The RPD layer was approximately 15 cm deep. Conspicuous species included the lug worm, *Arenicola marina*, various small polychaete worms and the bivalve *Macomangulus tenuis*. Station 2 is illustrated in Figure 117, Figure 118, Figure 119, Figure 120, Figure 121 and Figure 122 below.

Spatial variability observed

The only area where bait digging was observed was in an area approximately 800 m east of Black Pill (see description above). Due to the mobile sediment the UAV picked up little historic evidence of bait digging.

Persistence of bait digging

Only one visit was made to this site so it was not possible to measure persistence of bait digging impacts. Due to the mobile nature of the sand around Blackpill, it can reasonably be assumed that holes will not persist for long and probably no longer than a single tidal cycle. This was corroborated by bait diggers that were encountered on site.

Figure 114. Station 1, control hole 1 being dug with control hole 2 in background, 13/03/2020

Figure 115 Station 1 control hole 1, 13/03/2020

Figure 116 Station 1 control hole 2,13/03/2020

Figure 117 Station 2 comprised of fine and medium rippled sand with shell.

Figure 118 Close up of Station 2 sediment showing *Arenicola* holes and casts

Figure 119 Station 2 showing control holes with a view of the back of the shore

Figure 120. Station 2, control hole 1

Figure 121. Station 2, control hole 2

Figure 122 Station 2, control hole 3

Issues encountered

No issues were noted pertaining to access, UAV flights or field surveys at Swansea Bay. Previous bad weather in the survey season had not allowed this site to be visited and therefore a smaller area of the site was surveyed than previously anticipated.

4. Trialling using Local Relief Model (LRM) and Shaded Relief Model (SRM) for identifying bait digging at the Gann

The aerial images taken at the Gann were processed in GRASS (Geographic Resources Analysis Support System) to generate LRM and SRM images for the same area. LRM was generated using the r.local.relief GRASS module using a neighbourhood size of 51. SRM was generated using the r.relief GRASS module using an altitude of 45° and an azimuth of 315°.

This part of the Gann Flats was selected as a trial because sediment is mostly dug over and there were some clumps of seaweed on boulders. For example, Figure 123 appears to show 3 weed covered rocks sitting in scoured hollows. The rest of the area has all had historic bait digging.

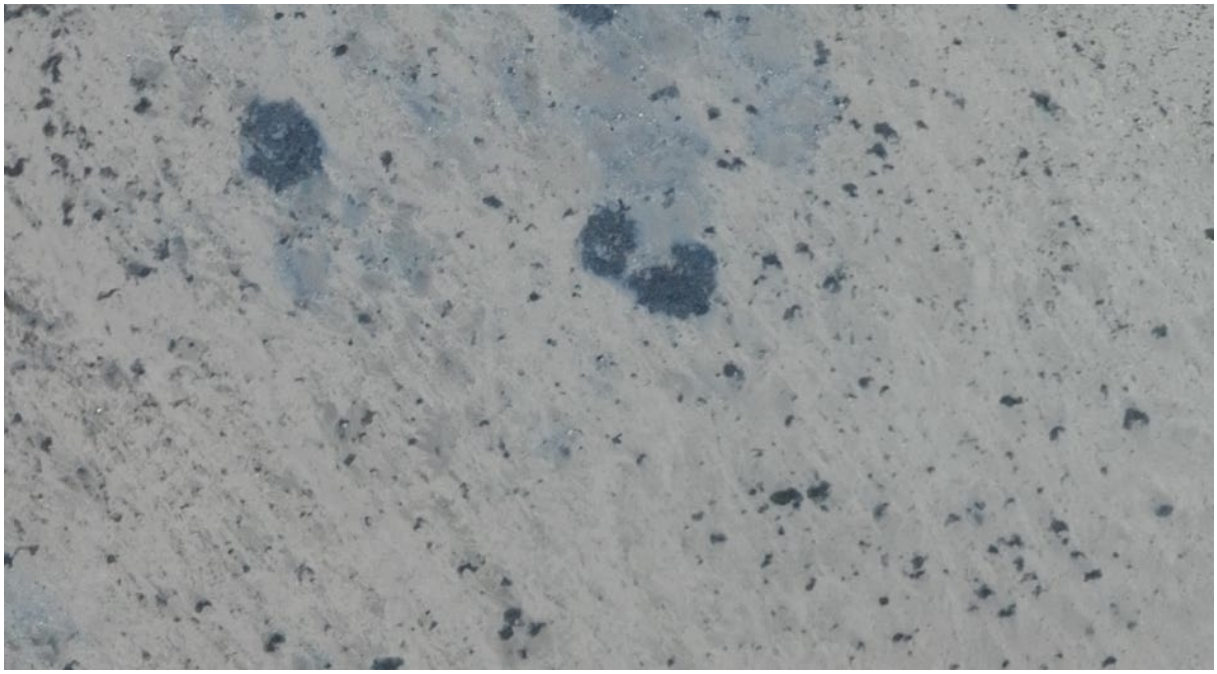


Figure 123 - Orthomosaic aerial image for a portion of the Gann Flats showing bait dug holes

The Shaded Relief Model (SRM) allows the altitude of the light source above the horizon, and significantly its azimuth (the angular distance from north) to be adjusted to try and highlight any shadows. Figure 124 shows the boulder depressions clearly but the whole of the rest of the area shows small undulations, probably caused from historic bait digging but also probably from pools and water runoff.

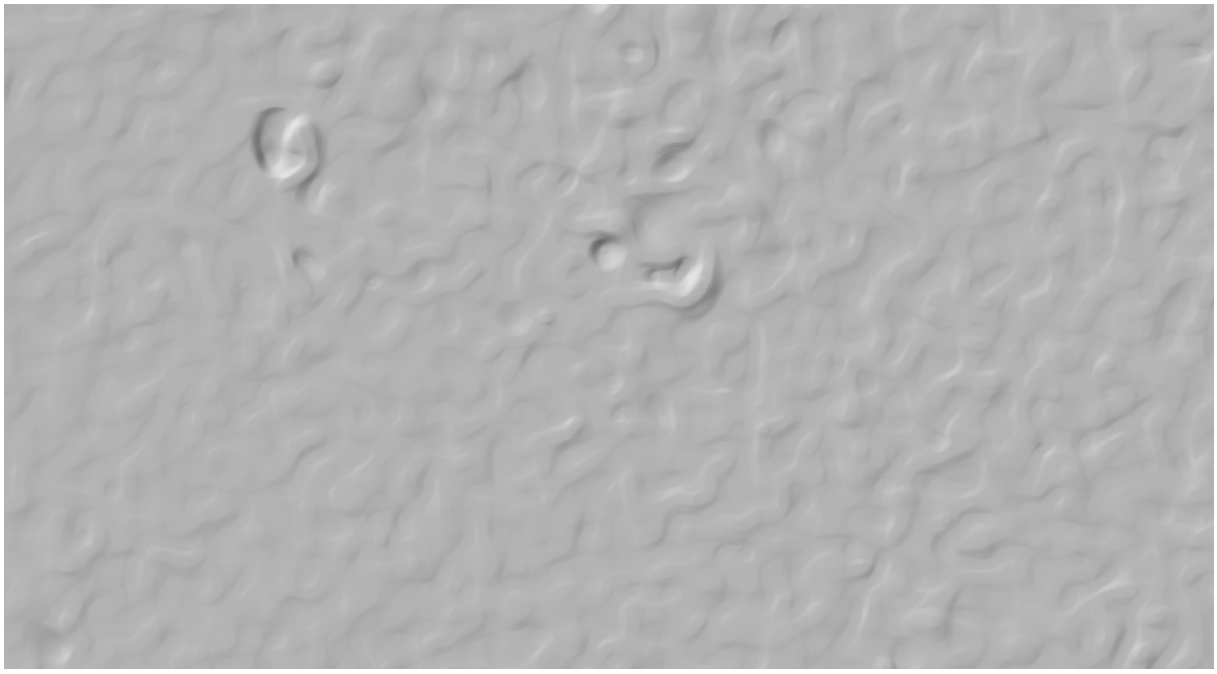


Figure 124 - Shaded Relief Model for the same area of the Gann Flats

Figure 125 shows the LRM (which highlights local changes in relief whilst trying to remove any background changes such as a sloping beach). The top left weed depression is very clear, showing how it can be useful in determining local relief changes. The rest of the image is fairly uniform and fails to distinguish between small variations in the sediment and bait dug areas. There is some slight suggestion that there is a pattern of wave ripples perpindicular to previling waves – but its subtle.

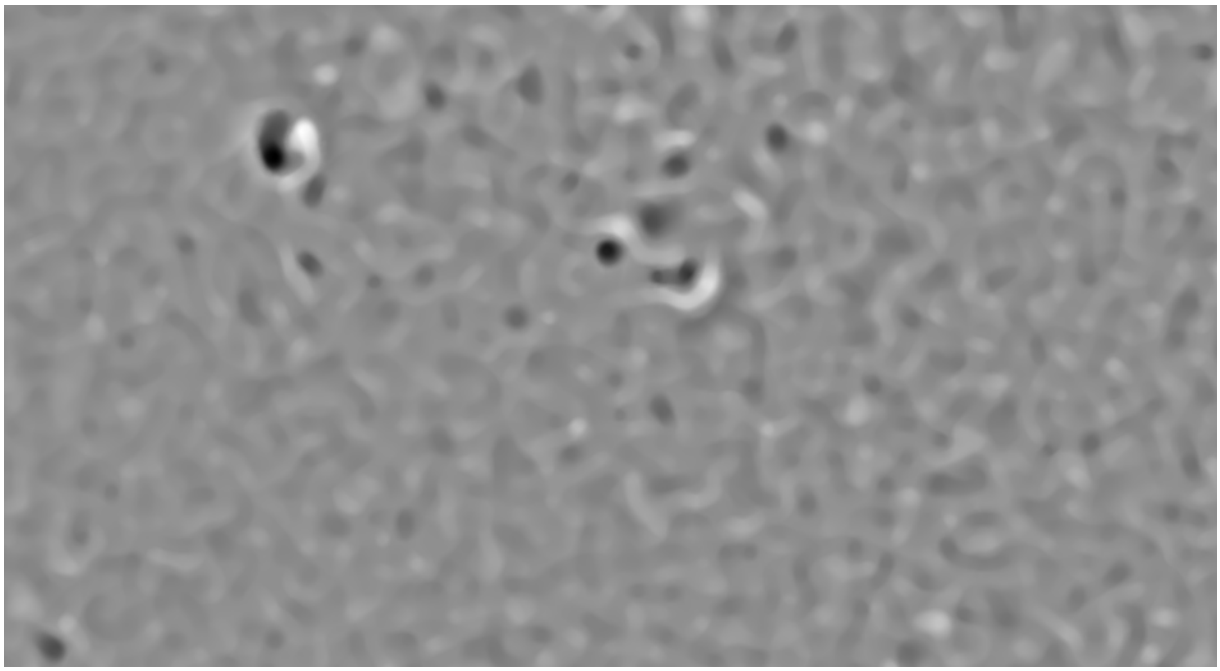


Figure 125 - Local Relief Model for a section of the Gann Flats. Black shows depressions.

Figure 126 and Figure 127 show the same area of Gann Flats. The band of seaweed on the strandline shows up well on both the aerial and the LRM. However there are also other very significant lumps in the top right of the LRM image where there is nothing on the aerial imagery. This might be an indication of bait digging, but such distinct changes would normally have a visible cause on the aerial imagery if bait digging was the cause. As can be seen from the strandline this is higher up the beach, in areas where bait digging is not expected, but distinct stippling is still visible on the LRM.

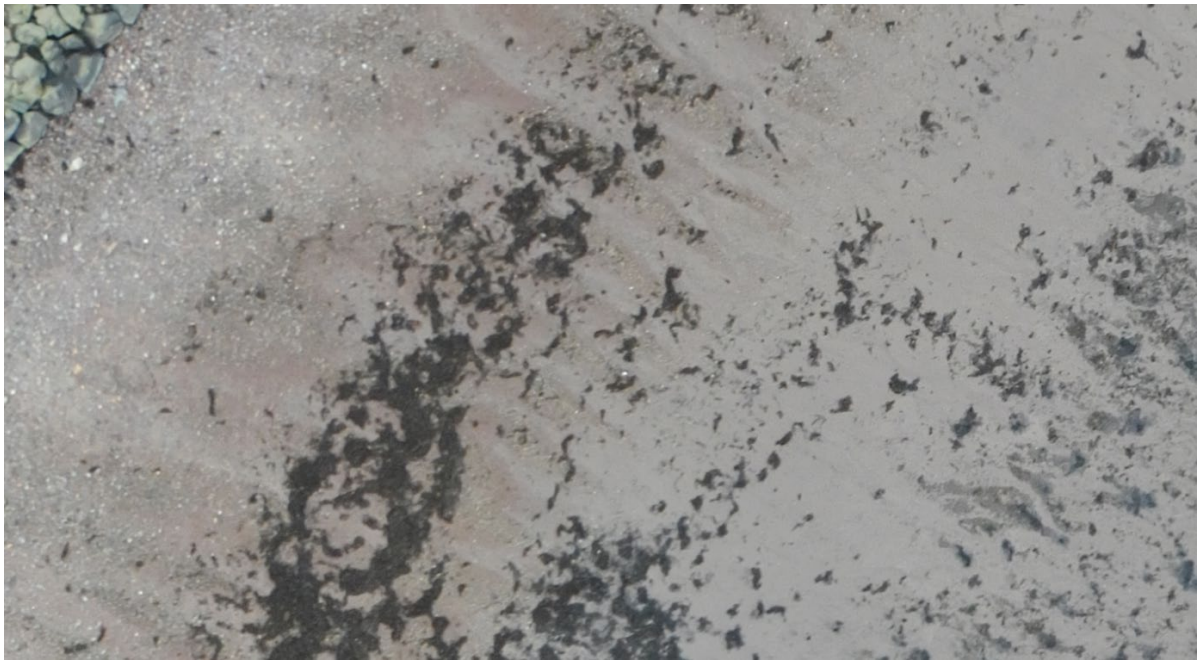


Figure 126 - Aerial imagery showing band of seaweed – but nothing obviously raised in top right to match LRM

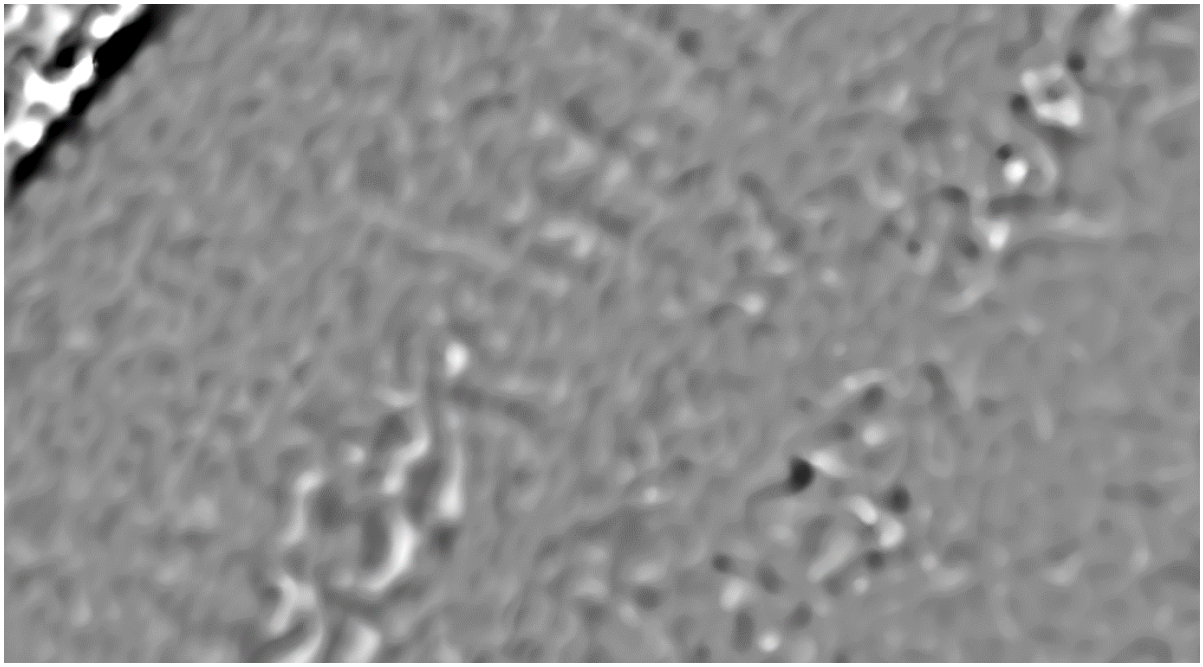


Figure 127 - LRM of a different section of Gann Flats showing raised area in the top right

5. Discussion

The aim of the project was to establish the suitability of aerial imagery taken from Unmanned Aerial Vehicles (UAVs) / drones, to investigate the spatial and temporal extent of bait digging and provide a snapshot at a point in time of bait digging at selected sites in north and south Wales. Ground truthing by experienced marine biologist field surveyors was used to improve the confidence when assessing the aerial imagery and provide further details about the impacts noted on the ground.

5.1 UAV imagery

Relatively cheap UAVs can now produce accurate high quality aerial imagery, which can then be used in GIS to digitise around areas of identified bait digging. The process of taking and generating orthomosaic aerial imagery is well established and this element of the project was relatively straight forward, although obtaining images of sediment shores at low water presented some specific challenges.

UAVs have restrictions from the CAA determining how they can legally be flown (see Section 0). Specifically, the distance a UAV can be flown from the operator means that on long stretches of beach a flight has to be undertaken in multiple stages.

In addition, the law changed during the project (30th November 2019) to strengthen the already strict regulations with regard to not flying near any controlled airspace. This is now built into the UAV software so often it is no longer sufficient to obtain permission to fly in controlled airspace. Permission has to be forwarded to the UAV manufacturer who then provide an unlock code to allow the UAV to enter the specific restricted area. As this process is in its infancy, the delay by manufacturers to provide unlock codes meant that there was insufficient time to get permission in time for this contract for some key sites. The DJI Phantom updated their software quickly, meaning it's now not possible to fly in restricted areas (https://www.dji.com/uk/flysafe/geo-map). The FlyBeePlus had not yet implemented geofencing in the software meaning it was possible to fly with permission from RAF Valley. It is likely that any future use of UAV in the vicinity of RAF Valley airfield or another controlled airspace will be challenging Figure 2and other methods of survey may be necessary instead or a longer run up time required to arrange the logistics of the survey.

UAVs also require reasonably calm conditions in order to obtain acceptable photographs. The maximum wind speeds they can fly in vary depending upon the make, but operating them close to their limits consumes much more power leading to shorter flight times and also can result in blurred images if the UAV is being buffeted by the wind. The senseFly Plus has an absolute maximum wind speed of 28mph but when allowing for gusts the average wind speed must be significantly lower.

Dry weather and reasonable light levels are also required. Even very thin cloud can significantly degrade the image quality. Undertaking such a survey during winter months posed significant challenges. A series of significant storms passed through the UK during this project with strong winds for much of the time making flying impossible (**Table 2**).

Tidal cycles in north Wales are such that spring tides are always early morning or in the evening. In winter, with reduced daylight hours available, a significant number of spring tides did not occur at a time when there was sufficient daylight.

Photographing in low light means the camera is forced to operate at slower shutter speeds increasing the risk of image blurring.

The DSM is determined by post processing the overlapping imagery taken by the UAV. The Pix4DMapper software attempts to identify the same point on adjacent images. A good DSM model (and hence a high accuracy orthomosaic image) relies on sufficient matching points being identified. Normally this is not an issue but uniform featureless sediment surfaces provide some unique challenges and it was uncertain how well this would work. Figure 6 - Example from the Gann Flats showing computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images.demonstrates that the number of matching points was lower on the sediment but there were enough features (boulders, stream edges) for the matching process still to work.

When creating orthomosaic images on land it is normally acceptable to complete the procedure over several days, if needed as matching feature are generally stable. With intertidal sediment shores it is important to complete within one tide in order to maximise the likelihood of getting sufficient matching points (a change to stranded seaweeds or the shape of a channel caused by a tidal cycle could cause image matching to fail).

Due to the conditions required to capture the orthomosaic issues, it would be a strong recommendation that future work was carried out over the summer months.

5.2 Bait digging activity

Identification from aerial

The maps showing the locations of bait digging are limited by:

- What is observable on the aerial imagery,
- How much bait digging has occurred recently,
- How long evidence of bait digging persists on a given shore.

The amount of detail that can be seen on aerial imagery is in part a result of quality of the imagery (see section 4.1). In addition, low light angles causing reflection limits what can be identified. On certain shores there were large amounts of water, sometimes pools from the tide and sometimes where streams appear to have been diverted by winter storms (e.g. Gann Flats).

Standing water makes it especially difficult to see the subtle depressions from historic bait digging, although a limited amount of water can help to highlight them. Winter storms may make it more likely that pools develop on shores and any streams running across the beach have higher volumes of water in winter.

The maps created showing the extent of bait digging evidence are likely to be an under representation of the total area impacted by this activity, especially if there has been wave action on the beach removing previous evidence.

Identification of bait digging areas is possible from the aerial imagery, but it is not an exact or straightforward process, especially when the evidence is for older digging. Ground truthing is important to improve accuracy, as patterns in the sediment and other artefacts can appear visually similar to historic bait digging, which in many cases may be resolved by visiting the site. It is important to visit each different shore at least once for shore survey in order to ground truth and “calibrate” the identification of bait digging areas from the aerial photography. Evidently the more extensive this initial ground truthing is, the higher the confidence will be in assigning bait digging evidence and more detailed maps are likely to be produced. It is likely that subsequent flights to the same shore may not need extensive ground survey as the “calibration” can be determined from the previous flight. If the shore had changed significantly due to storms or other factors a repeat ground truthing exercise might be useful.

A relatively low proportion of ‘new’ bait digging was identified on any of the shores visited. This is likely due in part to the time of year, as it is possible that less bait digging may be occurring over winter than during the summer months. Also, observational evidence suggest that the spoil heaps and deep depressions that allow newly dug holes to be separated from older digging evidence only persist for a few tidal cycles even on sheltered beaches with little wave action.

UAV imagery will only identify the most recent bait digging as “new”. The recording of large amounts of new bait digging is likely to be only that which has taken place in the preceding few days. This applies to all shores, but the exact number of preceding days will vary depending on sediment type, weather conditions etc. It would be useful to assess this, in the absence of extreme storm and heavy rainfall, which was experienced throughout the period of recording for this contract.

Maps of bait digging produced did not display a large proportion of ‘high’ intensity’ digging. While this may accurately represent the intensity of the digging at the site, it should be considered whether the scale of intensity could be adjusted to further pull out differences in activity within and between sites.

It should be considered whether any adjustments or modifications could be made to the methods used to represent the areas of bait digging at sites on maps, to ensure that the areas impacted by bait digging are displayed as clearly and consistently as possibly.

Distribution of bait digging

A summary of the extent of bait digging at the sites surveyed on different shore types is presented in Table 26.

Table 26 – Summary of recorded bait digging activity in all sites

Site name	Station	Sediment type	Shore exposure	Total Old bait digging (m^2) *	Total New bait digging (m^2) *	Total Bait Digging (m^2) (new and old)
Between Beaumaris and Penmon, Menai Strait	N/A	N/A	N/A	201,486	65	201,551
N/A	1	Fine muddy sand	Sheltered	N/A	N/A	N/A
N/A	2	Muddy sand	Sheltered	N/A	N/A	N/A
N/A	3	Fine sandy mud with scattered large boulders	Sheltered	N/A	N/A	N/A
N/A	4	Soft sandy mud with anoxic sub-layer	Sheltered	N/A	N/A	N/A
Penrhos Beach, Holyhead	1	Firm, rippled, mainly clean sand with sub-surface RPD layer	Fairly sheltered	7,082	7	7,089
Beddmanarch Bay, Holyhead	N/A	N/A	N/A	258,825	712	259,537
N/A	1	Fine sandy mud	Very sheltered	N/A	N/A	N/A

Site name	Station	Sediment type	Shore exposure	Total Old bait digging (m^2) *	Total New bait digging (m^2) *	Total Bait Digging (m^2) (new and old)
N/A	2	Fine sandy mud with coarse gravel sub-layer	Very sheltered	N/A	N/A	N/A
Four Mile Bridge, Cymyran Strait.	1	Soft muddy sand with a coarse gravel sub-layer	Ultra sheltered	2,712	528	3,240
Llanfair yn Neubwll, Cymyran Strait.	1	Soft, sticky sandy mud	Ultra sheltered	48,688	972	49,660
Inland Sea, Cymyran Strait.	N/A	*Zostera noltei* beds in littoral muddy sand	Ultra sheltered	Not flown or mapped	Not flown or mapped	N/A
Y Foryd Estuary, Menai Strait	1	Fine rippled sand with sub-surface black layer	Very sheltered	335,933	69	336,002
Gann Flats, Milford Haven	1	Soft muddy gravel	Very Sheltered	140,872	264	141,136
Sandy Haven, Milford Haven	1	Muddy sand	Extremely Sheltered (in pill)	3,424	325	3749
Gelliswick Bay, Milford Haven	1	Fine muddy sand	Sheltered	41	23	64

Site name	Station	Sediment type	Shore exposure	Total Old bait digging (m^2) *	Total New bait digging (m^2) *	Total Bait Digging (m^2) (new and old)
Angle Bay, Milford Haven	N/A	N/A	Very Sheltered	293,970	243	294,213
N/A	1	Muddy sand	N/A	N/A	N/A	N/A
N/A	2	Rippled medium fine sand	N/A	N/A	N/A	N/A
Swansea Bay	N/A	N/A	Moderately exposed	82,053	796	82,849
N/A	1	Medium to fine rippled sand and shell	N/A	N/A	N/A	N/A
N/A	2	Medium to fine rippled sand and shell	N/A	N/A	N/A	N/A
Total (old and new)	N/A	N/A	N/A	1,375,086 (137.5 ha)	**4,004** **(0.4ha)**	N/A
Total combined	N/A	N/A	N/A	N/A	N/A	**1,379,090m^2** **(137.9ha)**

* Totals are for all confidence levels (High to Very low)

Bait diggers were noted on 7 of the 12 shores visited during this survey, although relatively low number of individuals were observed at any one shore. In north Wales, this may in part be due to the early hours that many of the shore surveys had to be undertaken. It seems likely that there may be less bait digging occurring over winter, which may link to a probably reduced amount of angling that takes place over winter months, especially if bait is being sold to shops that supply the visitor market.

Impacts of bait digging have been noted in habitats which are listed under Section 7 (of the Environment (Wales) Act 2016), which include *Zostera notlii* (Seagrass), Sheltered muddy gravels and Intertidal mudflats. All of the sites surveyed have one or more of these protected habitats present, apart from Penrhos Beach and Gelliswick. Sheltered muddy gravel is a particularly diverse habitat typically occurring in areas protected from wave action. Sites that had sheltered muddy gravel habitats that overlap with bait digging activity include, Gann Flats and Four Mile Bridge and Angle Bay (seagrass also present at Angle).

All of the sites surveyed and showing signs of bait digging (apart from Penrhos Beach) are located within either a Special Area of Conservation or / and SSSI. The majority of these are in part designated for their sediment habitats, or support birds which are dependent on these habitats.

It is indicated from this survey that bait digging is more common in areas that are easily accessible. This includes not just access to the beach itself, but also ease of walking across the beach and height on the shore. For example, at Beaumaris there was more evidence of bait digging relatively close to the road / car parking and this is similar in Sandy Haven and Y Foryd, which had evidence of new digging was close to parking and access points

This study attempted to gain imagery at or close to spring low water so that the maximum amount of beach was exposed. The evidence from the maps presented in this report suggest that there is little bait digging on the lower extremities of the beach, probably due to both the effort required to reach these areas but also that on many tides the area is not exposed. This could mean that future studies could use a wider range of tidal heights and still capture the majority of the dug area. This would make flight and ground survey logistics more flexible.

Persistence of bait digging

The persistence of bait digging evidence on a particular shore is determined by:

- Sediment type of shore
- General exposure of shore
- Frequency and direction of any significant weather events
- The state of the tide when wave action hits the beach
- The persistence of bait digging evidence was shown to vary significantly from shore to shore. The results from the trial holes are shown in Table 27.

Table 27 – Summary of persistence of trial holes and likely persistence of damage

Site name	Station	Sediment type	Shore exposure	No of days between visits	Appearance of trial hole on return visit	Estimated persistence of visible damage at site
Between Beaumaris and Penmon, Menai Strait	1	Fine muddy sand	Sheltered	162 days	Test holes faintly apparent with coarser material where the spoil heap was. Fucoid cobble in one of shallow remains of the test hole	Weeks to months
N/A	2	Muddy sand	Sheltered	162 days	No obvious trace of the test holes. Much smoother than initial observations	Weeks
N/A	3	Fine sandy mud with scattered large boulders	Sheltered	162 days	Test holes apparently blended with other existing depressions.	Weeks
N/A	4	Soft sandy mud with anoxic sub-layer	Sheltered	162 days	Test holes still apparent in soft muddy sediment.	Weeks to months
Penrhos Beach, Holyhead	1	Firm, rippled, mainly clean sand with sub-surface RPD layer	Fairly sheltered	N/A	Not revisited	Likely to be days due to coarse sediment

Site name	Station	Sediment type	Shore exposure	No of days between visits	Appearance of trial hole on return visit	Estimated persistence of visible damage at site
Beddmanarch Bay, Holyhead	1	Fine sandy mud	Very sheltered	128	Test holes apparent, now with fucoid cobbles in 1 hole	Months to possibly years
N/A	2	Fine sandy mud with coarse gravel sub-layer	Very sheltered	128	Test holes clearly apparent. Fucoid cobbles in holes	Months to possibly years
Four Mile Bridge, Cymyran Strait.	1	Soft muddy sand with a coarse gravel sub-layer	Ultra sheltered	115	Area heavily dug; test holes possibly still apparent	Months to years if not over dug
Llanfair yn Neubwll, Cymyran Strait.	1	Soft, sticky sandy mud	Ultra sheltered	115	Test holes clearly apparent	Months to possibly years
Inland Sea, Cymyran Strait.	N/A	*Zostera noltei* beds in littoral muddy sand	Ultra sheltered	Not revisited	N/A	N/A
Y Foryd Estuary, Menai Strait	1	Fine rippled sand with	Very sheltered	135	Test holes no longer apparent	Weeks to months

Site name	Station	Sediment type	Shore exposure	No of days between visits	Appearance of trial hole on return visit	Estimated persistence of visible damage at site
		sub-surface black layer				
Gann Flats, Milford Haven	1	Soft muddy gravel	Very Sheltered	107	Visual evidence of previous holes is not immediately obvious.	Weeks to months
Sandy Haven, Milford Haven	1	Muddy sand	Extremely Sheltered (in pill)	107	Holes were still clearly visible and had been slightly enlarged by scour over this time.	Months to years
Gelliswick Bay, Milford Haven	1	Fine muddy sand	Sheltered	106	Holes had largely filled in, although the location of one of one holes could be identified by a ring of gravelly substrata in the holes previous location	Months
Angle Bay, Milford Haven	1 2	Muddy sand Rippled medium fine sand	Very Sheltered	107	Holes were no longer visible but still represented by soft liquid sediment	Months
Swansea Bay	1&2	Medium to fine rippled sand and shell	Moderately Exposed	N/A	Not revisited	Likely to be days due to coarse sediment and level of exposure

Table 27 shows that sites with sandier sediments, such as Y Foryd (and likely Pehrhos Beach and Swansea Bay), will not retain bait digging evidence for more than a few tidal cycles to weeks, possibly months. More sheltered sites, muddier sites, such as Beddmanarch Bay, show evidence of bait digging for at least 4 months, although the obvious spoil heap disappears within a week making identification of fresh activity difficult. Ultra sheltered sites in the Cymyran Strait still showed evidence of bait digging nearly 4 months after the holes were created and impacts from digging are likely to persist months (and probably years) later.

The lack of persistence of visual evidence of bait digging (meaning it can no longer be seen on an aerial photograph and often on the ground), does not mean the shore has recovered. There were instances where the control holes visually appeared to have disappeared and yet the sediment was clearly significantly altered still (e.g. Angle Bay– see Figure 104 and Figure 105), with subsequent impacts on the habitat structure and function.

It would be valuable to know more accurately the speed at which holes decay at different sites. This would be a relatively easy study to undertake and would allow for more accurate aging of holes. The current study only allowed for one repeat visit after several months. In summer, this might provide a reasonably accurate way of aging holes, though any sever weather event has the potential to “reset” a beach which is much more likely to occur during winter months.

Bait digging causing change of habitat

Bait digging has been noted to cause a number changes to affected shores, many of which have been documented first hand in this contract.

A consequence of bait digging little reported but reported here was the ability of bait holes to 'catch' semi-mobile algal covered stones. When shores had seaweeds attached to semi-mobile cobbles, these were documented as lodging in bait digging holes, including the control holes. This is likely to only occur at the more sheltered sites where there is insufficient wave action to remove the cobble once settled in the hole. During this contract, this was seen at Beddmanarch Bay (Figure 39 and 43, where *Ascophyllum nodosum and fucoids* growing on cobbles appears to have lodged in holes). This was also noted at Beaumaris to Penmon. This is then likely to cause localised scouring and presumably prevents the sediment from recovering to its previous pre-dug state. This phenomenon is likely to be widespread in areas with fucoid boulder and cobble habitats adjacent to bait dug sediment. In time, this may change the area from a purely sedimentary shore to one which is interspersed with cobbles and algae.

There was also evidence at Angle Bay and Four Mile Bridge where, on the follow up visit, the trial hole was almost invisible to the naked eye but the sediment in the hole was extremely soft. Digging holes creates piles of sediment and when left, the finer particles wash back into the holes leaving coarser sediments such as gravel on the surface. The result has been an extensive patchwork of firm sediment with very soft almost liquid sediments filling old holes. This represents an important change in sediment structure to certain shores. Such evidence will not be visible on aerial photographs, making ground truthing an important aspect of the survey to appreciate any impacts of bait digging. Digging is occurring in the *Zostera* (seagrass) bed at Angle Bay, and the damage to the bed is largely unknown and currently unquantified.

5.3 Testing the use of Local Terrain Models and Shaded Relief Models

These models were only tested in a few geographic areas as it didn't constitute the main part of the study. It can clearly be seen (Figure 124 and Figure 125) that the technique achieves its aim of being able to clearly identify small localised height differences on a shore.

Unfortunately, due to other features on the shore such as stranded seaweed, cobbles, streams and ripples, the bait digging evidence itself doesn't uniquely stand out. Also, any holes that fill with water do not show up as holes.

It may, on some occasions, provide an additional confidence when identifying an area from the aerial imagery but this technique would not be reliable in its own right. A further trial, when there is much less surface water, may prove this method to be more reliable.

It would be interesting to retry the technique on an area that had much more active bait digging occurring. It is possible that it would pick up fresh bait digging more reliably if the spoil heaps had not been too flattened out by tides.

There is a significant processing overhead to producing the LTM/SRM layers, but if this allowed fresh holes to be semi automatically identified using image processing techniques it could have value.

5.4 Summary of key findings, recommendations and further studies

Key findings and recommendations (methods/data presentation)

- Aerial imagery taken from a UAV is a valuable tool for capturing large areas of shore for later processing. However, they do have specific limitations; dry weather, adequate light levels and low windspeed.
- Working at spring low waters in winter (especially in North Wales) posed significant challenges. Future surveys should, in addition, be carried out over summer when better weather and longer daylight can be expected. It is likely in some locations there could be more bait digging activity during summer months if bait is collected for the visitor market.
- Locations with CAA flying restrictions (near airfields) can cause significant logistical complications when surveying using UAVs. This may be partially improved when manufacturers improve approaches to remove geo fencing with permission. Future areas identified to be surveyed in areas of restricted airspace may need a longer lead in time for survey planning and / or survey on foot instead.
- Water run off on a beach has been shown to obscure evidence of bait digging on aerial imagery. This should be considered when assessing whether a drone is the most appropriate method of mapping bait digging at these sites.
- Local Terrain Models (LTMs) and Surface Relief Models (SRMs) were shown to clearly identify small localised height differences on a shore but could not distinguish between bait digging and other shore features. A small specific study on the use of these models could be considered for future work, as although expensive, could prove a useful method of mapping bait digging at some sites.
- The current contract did not allow for frequent flights to be made. This is needed for a longer time series to be established and would be important for building up a picture of the impact at a site.
- Using aerial photography to map bait digging on mobile sandy shores captured very little digging activity. Future survey using UAVs should focus on shores where the substratum allows for longevity of bait digging holes.
- Ground-truthing was identified as an important element of mapping bait digging, as mapping damage from aerial imagery alone is not as strong as a combination of the two methods. Future work should consider using a combination of aerial imagery and shore survey to produce more accurate maps and improve the confidence of the imagery.

- Little evidence of bait digging was recorded on the extreme lower shore (likely due to lack of tidal exposure), which suggests future surveys could take advantage of a wider range of tides.
- Maps of bait digging produced did not display a large proportion of 'high' intensity' digging. While this may accurately represent the intensity of the digging at the site, it should be considered whether the scale of intensity could be adjusted to further pull out differences in activity within and between sites.
- It should be considered whether any adjustments or modifications could be made to the method of representing the areas of bait digging at sites, to ensure that the areas impacted by bait digging are displayed as clearly and consistently as possible between sites.

Key findings (site observation and persistence of damage)

- Bait digging evidence was found at all of the sites surveyed, which are considered to represent the most heavily dug areas that NRW are currently aware of in Wales.
- Bait digging appeared to be more intense in areas with easier access and parking.
- Impacts of bait digging have been noted on habitats which are listed under Section 7 (of the Environment (Wales) Act 2016, and include *Zostera notlii* (Seagrass), Sheltered Muddy Gravels and Intertidal Mudflats and Sandflats The majority of these sites are within MPAs.
- A total of 137.9 ha (all ages and confidences) of bait dug sediment was recorded at the 12 sites. The site with the greatest total area of digging was 33.5 ha on Y Foryd Estuary (although much of the area identified as bait dug was of low confidence). The site with the smallest recorded area was Gelliswick, with evident digging being concentrated in a localised area.
- Evidence of recent digging was recorded at all sites except Penrhos Beach, Anglesey.
- Bait diggers were recorded actively digging at 7 of the 12 sites during the visit.
- Bait digging has been noted in this survey to cause a number of impacts to the shores surveyed. These include;
    - Semi-mobile cobbles with seaweed getting 'caught' in bait holes and which has the potential to change the habitat (see Section 3.1.4.2, 3.3.2.5, 3.3.3.6). It would be of interest to carry out further studies on this.
    - Holes filling with soft sediment, leading to a series of depressions of softer sediment then the surrounding shore.
    - Gravel being brought up to the surface of the shore from the act of digging, creating artificially gravelly and cratered landscape.

- Persistence of bait digging evidence varied from shore to shore. Visible damage lasted longest at shores which were sheltered / extremely sheltered, and holes remained clearly visible at some of these sites after approximately 4 months.
- Visible damage disappeared most quickly on shores which were composed of sand / coarse sand and were more exposed, with holes reported by bait diggers as disappearing in a day or two.
- The winter of 2019/20 was considered exceptionally stormy and was likely to have resulted in wave action on sites which would not normally expect it and result in unusual smoothing of otherwise sheltered habitats.

Recommendations for future studies

- Further independent studies on the significance of damage caused on shores of different wave exposures and sediment types, would elucidate whether further studies are necessary. It would be useful to confirm the short term nature of sediment disturbance and ecological recovery in sandier, more wave exposed sites.
- Further use of the UAV (accompanied by a level of ground truthing), during summer months, to confirm the effectiveness of this method to map bait digging, as well as extend our understanding of levels of bait digging intensity on wave sheltered sites, where holes are known to persist. A better measure of hole persistence, outside of extreme storm and rainfall events on the wave sheltered sites would also be useful.
- Further observations on the occurrence and frequency of semi-mobile, seaweed covered cobbles and boulders landing in bait holes, influencing site recovery from bait digging, would be beneficial. This activity has the potential to cause long term changes in habitat. This may suit an honours or part of a master's project.
- A further specific study on the use of the use of Digital Surface Models may be beneficial as there is the potential that they may be useful in mapping bait digging on large areas of the shore. Studies should be undertaken in a discrete areas with little surface water and recent digging to test methods.
- It should be considered whether these selected sites represent the most impacted areas of bait digging or whether additional sites in Wales should be surveyed in future.
- The relationship between digging and angling competitions was not taken into account during this study, but specific events could lead to large scale collection at certain locations at certain times which could be further investigated.
- The results of this study can be used to help prioritise those sites that suffer the most extensive bait digging for future investigation or are the most damaged based on the habitats which are present.
- This study provides important evidence required to inform possible future management of sites to the activity of bait digging in Wales.

6 References

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Glossary

Abbreviation	Description
CAA	Civil Aviation Authority
DSM	Digital Surface Models
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System
LRM	Local Relief Model
JNCC	Joint Nature Conservation Committee
MNCR	Marine Nature Conservation Review
NRW	Natural Resources Wales
PPK	Post-Processed Kinematic
RPD	Redox Potential Discontinuity
RTK	Real-Time Kinematic
SRM	Shaded Relief Model
UAV	Unmanned Aerial Vehicles

Data Archive Appendix

Data outputs associated with this project are archived under metadata number NRW_DS124806 on server–based storage at Natural Resources Wales.

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] A series of Pix4D generated (PDFs) which detail each flight undertaken and the subsequent image processing.

Beaumaris_North_report.pdf

Beaumaris_South_report.pdf

PenrhosBay_report.pdf

Beddmanarch North_report.pdf

Beddmanarch Centre_report.pdf

Beddmanarch South_report.pdf

Four Mile Bridge_report.pdf

Llanfair yn Neubwll_report.pdf

Foryd_report.pdf

Gann_report.pdf

Sandy Haven_report.pdf

Gelliswick_report.pdf

Angle_report.pdf

Swansea_Report.pdf

[C] GIS layer created from the .tiff files on which the maps in the report are based

BaitDiggingAreas_2019_2020.shp

[D] A full set of image files produced in geoiff format.

Beaumaris_North_20191001.tif

Beaumaris_South_20191001.tif

PenrhosBay_20191002.tif

BeddmanarchNorth_20191028.tif

BeddmanarchCentre_20191028.tif

BeddmanarchSouth_20191028.tif

FourMileBridge_20191110.tif

LlanfairYnNeubwll_20191110.tif

Foryd_20191027.tif

Gann_20191128.tif

SandyHaven_20191128.tif

SandyHaven_20191128.tif

Gelliswick_20191129.tif

Angle_20191129.tif

Swansea North_20200313

Swansea South_20200313

[E] Field reports (Word)

20191003 Field report Beaumaris and Penrhos Bay.docx

20191030 Field report Foryd and Beddmanarch.docx

20191110 Field report Neubwll Four Mile Beddmanarch.docx

20200305 Field report repeat visits Neubwll Four Mile Beddmanarch.docx

20200310 Field report Foryd and Beaumaris.docx

20191110 Field report Pembrokeshire.docx

[F] Digital Surface Models for the 12 sites (DSMs) are stored in NRW archive

To access the data that accompanies this report please contact NRW Data Distribution Team datadistribution@cyfoethnaturiolcymru.gov.uk. Some of this data may be able to be supplied to you.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue https://libcat.naturalresources.wales (English Version) and https://catllyfr.cyfoethnaturiol.cymru (Welsh Version) by searching 'Dataset Titles'

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