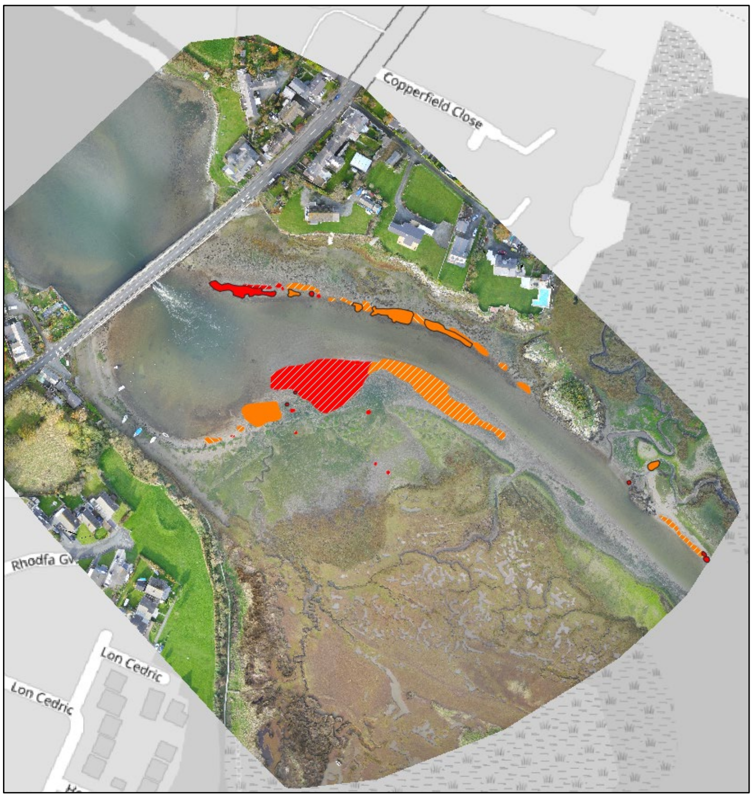
Bait Digging Evidence Collection - Methodology Review



Report No: 603

Author Name: West, V., Robbins, K., Frost, N., Hull, S.

Author Affiliation: ABPmer

About Natural Resources Wales

Natural Resources Wales' purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales' well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence-based organisation. We seek to ensure that our strategy, decisions, operations and advice to Welsh Government and others are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- 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.

This Evidence Report series serves as a record of work carried out or commissioned by Natural Resources Wales. It also helps us to share and promote use of our evidence by others and develop future collaborations. However, the views and recommendations presented in this report are not necessarily those of NRW and should, therefore, not be attributed to NRW.

Report series:	NRW Evidence Report
Report number:	603
Publication date:	April 2022
Contractor:	ABPmer
Contract Manager:	Grant, L.
Title:	**Bait Digging Evidence Collection Methodology Review**
Author(s):	West, V., Robbins, K., Frost, N., Hull, S.
Technical Editor:	Frost, N.
Quality assurance:	Tier 3
Peer Reviewer(s)	Grant, L and Hatton-Ellis, M
Approved By:	Lewis, M
Restrictions:	None

Distribution List (core)

NRW Library, Bangor	2
National Library of Wales	1
British Library	1
Welsh Government Library	1
Scottish Natural Heritage Library	1
Natural England Library (Electronic Only)	1

Recommended citation for this volume:

West, V., Robbins, K., Frost, N., Hull, S. 2021. Bait Digging Evidence Collection Methodology Review. NRW Evidence Report Series Report No: 603, 29pp, NRW, Bangor.

Contents

List of Figures

List of Tables

1 Crynodeb Gweithredol

Yn 2019, cynhaliwyd arolwg Cerbyd Awyr Di-griw (UAV) i amcangyfrif cwmpas a dwysedd palu am abwyd ar 12 safle ar draws Cymru. Roedd Adroddiad Tystiolaeth CNC 449 (Perrins *et al.,* 2020) yn asesiad a roddodd gryn dipyn o wybodaeth, a dyma'r cam cyntaf i archwilio'n drylwyr i balu am abwyd ar lannau Cymru. Comisiynwyd ABPmer gan CNC i adolygu'r fethodoleg a ddefnyddiwyd yn Perrins *et al.* (2020) ac i nodi technegau eraill posib ar gyfer mesur cwmpas a dwysedd palu am abwyd ar lannau Cymru.

Yn gyntaf, adolygwyd manteision ac anfanteision y fethodoleg sy'n defnyddio dronau yng nghyd-destun pa mor effeithiol yw hi, a pha mor gadarn yw'r data ar gyfer amcangyfrif cwmpas a dwysedd palu am abwyd ar hyd glan. Wedyn cynhaliwyd adolygiad o'r llenyddiaeth ar astudiaethau lleol a rhyngwladol er mwyn nodi dulliau amgen sydd wedi'u defnyddio i archwilio effaith palu am abwyd neu weithgareddau hamdden eraill ar y lan a'u heffeithiolrwydd yn gyffredinol. Yn olaf, defnyddiwyd barn arbenigol i awgrymu methodolegau y gellid eu defnyddio yn y dyfodol i gael arolygon cost effeithiol a chywir o gwmpas a dwysedd palu am abwyd yn ogystal ag argymhellion ar gyfer arolygon yn y dyfodol.

Cafodd yr adolygiad o Perrins *et al.* (2020) bod defnyddio UAV yn galluogi cofnodi gweithgarwch palu am abwyd ar hyd glannau cyfan mewn cyfnod cymharol fyr gan ddefnyddio methodoleg safonedig, ond bod angen, serch hynny, amodau tywydd da ar yr un pryd ag amodau golau da a llanw isel. Yn ogystal, roedd angen cryn dipyn o waith i gadarnhau cywirdeb drwy gyfrwng arsylwadau maes. Er bod UAVs yn ffordd effeithlon o gasglu llawer o ddata mewn cyfnod byr, mae'r angen i wneud arolygon maes er mwyn cadarnhau cywirdeb canlyniadau UAV yn gwneud y dull hwn yn llawer mwy costus o ran arian ac amser.

Gellir defnyddio dulliau arolwg maes i asesu adferiad tyllau wedi'u palu am abwyd ac amcangyfrif dwysedd tyllau wedi'u palu ar draws ardaloedd dwysedd uchel, canolig ac isel ac o fewn gwahanol fathau o waddodion/cynefinoedd. Yn ogystal, gall dulliau maes roi gwybodaeth na ellir ei hasesu drwy gyfrwng y fethodoleg UAV, er enghraifft mân dueddiadau amseryddol (cylch y llanw neu'r diwrnod) o ran ymdrechion a chwmpas palu am abwyd a nodweddion safleoedd fel y mathau o ecoleg a gwaddodion ar y lan. Er bod potensial i ddata hynod fanwl gael ei gasglu drwy gyfrwng arolygon maes, mae dulliau o'r fath yn aml yn gostus o ran amser ac arian.

Gellir defnyddio camerâu sefydlog i gael mesur costeffeithiol o ymdrechion palwyr am abwyd, er enghraifft nifer y palwyr sy'n ymweld â'r lan drwy gydol y dydd neu gylch y llanw, ac amser cyffredinol ar y lan i bob palwr. Gallai data o'r math hwn helpu tuag at danlinellu'r amrywioldeb potensial o ran dwysedd palu am abwyd dros y tymor hir. Gellid defnyddio'r fethodoleg hon hefyd i asesu effeithiau tarfu yn sgil palu am abwyd ar rywogaethau o adar. Os caiff mesurau rheoli eu gweithredu i leihau effaith palu am abwyd, gellid defnyddio camerâu sefydlog hefyd i annog gorfodaeth ac asesu cydymffurfiad.

Fodd bynnag, fel yn achos delweddau UAV, mae ansawdd y delweddau'n ddibynnol iawn ar y tywydd a'r golau, a gall y cwmpas fod yn gyfyngedig yn enwedig ar draws safleoedd mwy. Felly, mae sut caiff y camera ei leoli ar y lan yn dylanwadu'n fawr ar ansawdd y data.

Roedd manteision ac anfanteision yn gysylltiedig â phob methodoleg a adolygwyd yn yr adroddiad hwn, ac mae'n debygol mai dull cyfunol a fydd yn galluogi meintoli cwmpas a dwysedd palu am abwyd yn y ffordd fwyaf cadarn. Defnyddio UAVs ar y cyd â dulliau arolwg maes yw'r cyfuniad gorau o fonitro sy'n effeithiol o ran arian ac amser ac sydd hefyd yn sicrhau lefel uchel o gywirdeb ar gyfer meintoli cwmpas, dwysedd ac ymdrechion palu. Lle bo modd, dylai arolygon yn y dyfodol geisio ail-greu'r astudiaeth a gynhaliodd Perrins *et al.* (2020) er mwyn cynyddu'n dealltwriaeth o amrywioldeb hirdymor palu am abwyd ar yr un 12 o lannau.

2 Executive summary

In 2019, an Unmanned Aerial Vehicle (UAV) survey was conducted to estimate the extent and intensity of bait digging on 12 sites across Wales. The NRW Evidence Report 449 (Perrins *et al.,* 2020) was a highly informative assessment and the first step in thoroughly investigating bait digging on Welsh shores. ABPmer was commissioned by NRW to review the methodology used in Perrins *et al.* (2020) and identify potential alternative techniques for measuring bait digging extent and intensity on Welsh shores.

Firstly, the benefits and limitations of the drone methodology were reviewed in the context of its efficiency, and the robustness of the data for estimating bait digging extent and intensity across a shore. A literature review of local and international studies was then undertaken to identify alternative methods which have been used to investigate the effect of bait digging or other recreational activities on the shore and their overall effectiveness. Lastly, expert judgement was used to suggest future methodologies that could be used to obtain cost effective and accurate surveys of bait digging extent and intensity along with recommendations for future surveys.

The review of Perrins *et al.* (2020) found that whilst the use of a UAV enabled bait digging activity to be captured across entire shores in a relatively short period of time using a standardised method, it required good weather conditions to coincide with good light conditions and low tide. In addition, it required significant amounts of ground truthing with field-based observations to ensure accuracy. Whilst UAVs are efficient at collecting a large amount of data in a short period time, the need for field-based surveys to ground truth the UAV result makes this method far more costly and time consuming.

Field-based survey methods can be used to assess the recovery of bait dug holes and estimate the density of dug holes across high, medium and low intensity areas and within different sediment/ habitat types. Field-based methods can additionally provide information which cannot be assessed with the UAV methodology, such as fine scale temporal (day or tidal cycle) trends in bait digging effort and extent and site characteristics such as the ecology and sediment types on the shore. Whilst there is the potential for highly detailed data to be collected through field-based surveys, such methods are often time and cost intensive.

Fixed cameras can be used to gain a cost-effective measure of bait digger effort, such as number of diggers visiting the shore throughout the day or tidal cycle, and overall time on the shore per digger. Data such as this could help towards highlighting the potential variability of bait digging intensity over the long-term. This methodology could also be used to assess the impacts of disturbance from bait digging on bird species. If management measures are implemented to reduce bait digging impact, fixed cameras could also be used to encourage enforcement and to assess compliance.

However, as with UAV imagery, image quality is heavily dependent on weather and light conditions and coverage can be limited particularly across larger sites, therefore data quality is heavily influenced by the positioning of the camera on the shore.

All methodologies reviewed in this report had benefits and limitations associated with them and it is likely that a combined approach will give the most robust quantification of bait digging extent and intensity. The use of UAVs in combination with field-based survey methods provide the best combination of cost and time effective monitoring whilst maintaining a high level of accuracy for quantifying digging extent, intensity and effort. Where possible, future surveys should aim to repeat the study undertaken by Perrins *et al.* (2020) to increase understanding of the long-term variability of bait digging on the same 12 shores.

3 Introduction

Bait collection has been an important part of coastal life for generations. The collection of bait by digging into the sediment has received considerable attention over the last 35 years by scientists, conservation agencies, local non-governmental agencies, and the government (Cryer *et al.,* 1987; Fowler *et al*., 1999; Watson *et al.,* 2017a) to understand the impacts on the foreshore. Bait digging is recognised to cause long-term changes to sensitive habitats and is of particular concern on certain shores across Wales.

In 2019, a survey was conducted to inform NRW of the extent and intensity of bait digging across 12 sites on the Welsh foreshore. The NRW Evidence Report 449 (Perrins *et al*., 2020) was the first step in thoroughly investigating bait digging across Wales. This survey included the use of a drone, also known as an Unmanned Aerial Vehicle (UAV), as a novel method to collect data. Due to the unknown reliability of this monitoring method, the survey required a high degree of ground truthing to ensure accuracy of the results.

ABPmer was commissioned by NRW to evaluate the methodology used in Perrins *et al*. (2020) to assess the accuracy of the results obtained and the reliability of UAVs as a technique to monitor bait digging. This was set in the context of alternative methodologies that could be used to obtain cost effective and accurate survey data of bait digging extent and intensity.

This review presents the benefits and limitations of the UAV methodology in the context of its efficiency and the robustness of the data for estimating bait digging extent and intensity across a shore. A literature review of local and international studies has also been undertaken to identify alternative methods for investigating the effect of bait digging, or other relevant recreational activities, on the shore. After evaluating the methods identified in the review, expert judgement was used to suggest future methodologies that could be used to obtain cost effective and accurate surveys of bait digging extent and intensity. Finally, recommendations for future surveys were made in terms of potential locations to target or additional data to collect.

4 Review of Bait Digging Monitoring Methods

This section provides a review of the survey methodology used in Perrins *et al.* (2020) to assess the accuracy of the results obtained and the reliability of UAVs as a monitoring technique to understand bait digging extent and intensity (Section 4.1).

A subsequent literature review has highlighted further key methods which are appropriate and effective for measuring the extent and intensity of bait digging on the foreshore. Overall, relatively few studies have quantified the extent and intensity of bait digging in the literature.

Therefore, studies which had different objectives, for example, investigating the effects of other onshore activities, such as recreational fishing, were also considered within the review. In summary, alternative methods include the use of field-based observations, fixed cameras and existing aerial imagery (see Sections 4.2, 4.3 and 4.4 respectively). All methodologies reviewed in this report have benefits and limitations associated with them which have been summarised in Section 4.5 and presented in Table 1.

4.1 Unmanned aerial vehicles (UAVs)

4.1.1 UAV survey method

During the winter of 2019-2020, Perrins *et al*. (2020) used a fixed wing UAV to capture orthorectified imagery of 12 sites across Wales (seven in north Wales, four in Milford Haven, and Swansea Bay). Each site was surveyed once at low water during spring tides when bait digging areas were considered to be fully exposed. The UAV was flown at a height of 120 m and photos from the attached camera equated one pixel to approximately 3 cm on the ground. The UAV followed a predetermined flight path for each site to ensure coverage of the entire study area.

In parallel to the UAV survey, an experienced marine biologist conducted a field-based survey at each site to collect data on the habitats, biotopes and species present. The age of holes and areas where bait digging was taking place was collected to ground truth the bait digging evidence identified by the UAV images. Further, experimental control holes which replicated bait digging holes were dug in areas where evidence of digging was identified. These holes were used to provide reference for the aerial imagery to identify the appearance of freshly dug holes. These sites were also revisited approximately 4 months later to understand the rate of recovery of the sediment.

To evaluate the extent and intensity of bait digging, a virtual raster was created for each site from the aerial imagery tiles. Polygons were used to map evidence of bait digging categorised by the intensity of digging, estimated age of the holes and confidence in assessment.

4.1.2 Benefits

It is clear from Perrins *et al*. (2020) that the use of the UAV provided a valuable tool for capturing high-resolution evidence of bait digging across a large area (an entire shore in most cases). It also provided a means to visually interpret and display the distribution of bait digging intensity. Aerial photography has been used in similar ways in other assessments of bait digging extent and intensity and has been suggested as an effective and efficient tool for surveying mudflats particularly due to the wide geographic range that they cover (Sypitkowski *et al*., 2010; Fearnley *et al.,* 2013).

The ability to collect data across large areas in a short period of time is hugely beneficial for surveys which are dependent on physical factors such as the tide. Therefore, the use of drones is likely a more efficient and cost-effective method than field-based observations, particularly on large shores which may require surveys to be completed over several days.

It is also important to acknowledge that the use of aerial photography provides a bank of images from which data can be collected, verified and archived for future analysis or investigations. Further, the archiving of such images increases the usability and cost-effectiveness of the information gathered if the images are made available to other researchers (McEvoy *et al.,* 2016).

4.1.3 Limitations

Prior to any survey commencing, to operate any UAV over 250 g in weight the operator is required as a minimum to:

- Be registered as an operator;
- Have completed DMARES Foundation Training/Test and Hold a Flyer ID; and
- Hold an A2 Certificate of Competency.

The Civil Aviation Authority (CAA) regulations have strict rules on the use of drones/ UAVs and some areas require special permission to fly, for example, within RAF 'no fly' areas. UAVs have also been pre-programmed with 'no fly' locations where it is impossible to take off or enter airspace, a map of the currently restricted locations around Wales is shown in Figure 1. This restriction meant the Inland Sea, Cymyran Strait was unable to be surveyed by Perrins *et al* (2020). There are also restrictions over Y Foryd Bay.

The application to fly in restricted locations is lengthy and difficult, requiring not only permission from the area subject to restrictions but also proof of this permission has to be sent to the manufacturer who then allows unlocking of that particular bit of airspace. Locations with flying restrictions present difficulties for the use of UAVs for surveys and it is likely these areas would need to be surveyed on foot. In addition to the above considerations, during flight the operator must:

- Remain a safe distance (50 m minimum) from people and not overfly assemblies of people; and
- Fly no higher than 120 m above the ground.

These factors must be considered in any pre-survey planning and design and could result in on-site changes to methodology or flight routes if members of the public are present.

Figure 1 UAV navigational restrictions within Wales (source: UK Aeronautical Information Service)

Perrins *et al.* (2020) mentioned that field-based ground truthing was vital for ensuring accuracy of bait digging extent and intensity from the UAV photographs. The field-based surveys identified both key areas of bait digging prior to image analysis and any patterns or artefacts in the sediment which could look similar to historic bait digging. Without field-based ground truthing, historic bait digging was likely very difficult to determine using aerial photography, thus the ground-truthing of the aerial images was a crucial part of the UAV methodology. It is therefore likely that the field-based surveys would need to be conducted at each new site to capture specific sediment variations and patterns. In this context it is likely that field-based ground truthing will always be required to some degree.

Whilst UAVs are efficient at collecting a large amount of data in a short period of time, the need for field-based surveys makes this method far more costly and time consuming. In addition, cost of the UAV equipment itself can be high, for example White *et al.* (2022) reported pre-survey staff training and UAV equipment costs of £14,045.

Analysis of bait digging extent and intensity by aerial photography is also limited by how long evidence of digging persists on a given shore. Perrins *et al*. (2020) used experimental holes dug to assess the recovery of the sediment. This provided a useful means to determine the uncertainty of the aerial photography by highlighting sites where bait digging extent and intensity were likely underestimated due to short-term recovery. Ultimately, data from the experimental holes highlighted that a combined approach is necessary to ensure a more robust evaluation of bait digging impact when using aerial photography.

The requirement for good weather, light and low wind conditions are one of the biggest drawbacks of using UAV methods. An ideal combination of dry, clear (i.e., no low-lying cloud/mist) and calm conditions are needed for flying a UAV and for the collection of high-quality, non-blurred photos. These conditions must also coincide with good light conditions in order to more confidently identify bait digging evidence in photos. Low light conditions lead to longer shutter speeds on the attached cameras increasing the likelihood that the images may become blurred.

The collection of data in the winter can present a challenge, as experienced by Perrins *et al*. (2020), where shorter day lengths are coupled with spring low tides which occur in the early morning or late afternoon, limiting suitable daylight hours. In addition, surveying between December to March resulted in Perrins *et al.* (2020) experiencing more frequent storms and rainfall, and therefore unsuitable flying conditions, than at other times of the year. The requirements for adequate survey conditions can therefore greatly limit the undertaking of aerial surveys and effect the ability to accurately identify bait digging evidence from photos (potentially causing an underestimation of bait digging on the shore). In Perrins *et al.* (2020), poor quality/blurry images were collected at Penhros Beach and Beddmanarch Bay as a result of low light conditions, which subsequently reduced the confidence in the assessment and the reliability of these results.

Whilst Perrins *et al.* (2020) allowed an initial evaluation of bait digging extent and intensity, it only captured the impact of bait digging during a single snapshot in time. Bait digging activities are likely to be variable over time and thus the current survey was not a representative measure of the overall impact on the shore. Additional surveys are needed which aim to repeat the study to understand the potential variability of the activity over time or with season on each shore. Ultimately, repeated surveying will allow for a more complete understanding of the long-term/seasonal vulnerability of the shore to bait digging. However, it has been acknowledged by Fearnley *et al*. (2013) that due to the requirement of good weather, light and low wind conditions coinciding with low tides, it can be very difficult to get consistent coverage from UAV monitoring when undertaking repeated surveys of one site over time.

4.2 Field-based observations

One of the simplest ways to quantify the intensity of bait digging holes is to count the number of holes per unit area of the shore (density of the holes). It is also preferable to collect these data over time to assess short and long-term variability of bait digging on the shore.

Field-based surveys conducted by Morrell (2007) estimated bait digging intensity by determining the location of all bait digging holes using Global Positioning Systems (GPS) and categorised the holes based on their estimated age. This survey was undertaken across seven different locations in Milford Haven and repeated across four seasons. The methodology in Morrell (2007) allowed for the collection of highly detailed data on the spatial distribution of bait digging, specifically bait digging intensity and extent on each shore. It is acknowledged, however, that such methodologies are time and cost intensive with large sites potentially requiring multiple days to survey. Where sites are large, or bait digging is intensive, stratified or systematic sampling could be used to quantify holes per unit area.

Shore observations can also provide additional data to supplement bait digging intensity and extent, such as number of diggers over the course of a day, harvesting tools and species of interest, which are more difficult or impossible to capture with aerial photography. In addition, field-based observations and sampling techniques can be used to collect data on the site characteristics, such as ecology, sediment type and location of sensitive habitats. For example, faunal and sediment sampling can be used to identify infaunal composition and sediment characteristics, which can provide further information on the sensitivity of the shore and its features.

Whilst bait digging can be assessed from field-based surveys through GPS mapping of digging boundaries it can be difficult to visually appreciate the extent across the shore on foot, at larger sites this might also be very time consuming especially in comparison to aerial methods. In addition, lower shore access at some sites may be limited resulting in difficulties in mapping the extent of the boundary of bait digging activity. Aerial footage provides a clear overview of the extent of bait digging (Fearnley *et al.,* 2013). The collection of observational data such as from GPS or walk-over surveys/line transects provides a highly robust and repeatable way of ground truthing aerial surveys. This can be used to further inform the classification of high and low intensity dug areas with greater confidence as well as identifying historic bait digging which is not as easily captured through photography.

4.3 Fixed cameras

Fixed cameras, including closed-circuit television (CCTV), time-lapse cameras and webcams have been used to investigate near shore activities such as bait digging and recreational fishing (Keller *et al.,* 2016; Lancaster *et al.,* 2017; Watson *et al.,* 2017a).

Watson *et al*. (2017a) successfully measured the extent of bait digging activities on the south coast of the UK using remote CCTV cameras which recorded the number of bait diggers on the shore over a 14-day period. This method allowed Watson *et al.* (2017a) to identify that bait digging effort and intensity was high, with a mean of 3.14 bait diggers per tide (both day and night) with individuals digging for up to 3 hours per tide. Watson *et al.* (2017a) noted that CCTV is an everyday part of many people’s lives and recent advances in technology and reductions in price means it offers a cost-effective solution to assess bait digging activities and provide enforcement of management activities.

Lancaster *et al.* (2017) used fixed trail cameras to quantify recreational non-compliance in rockfish conservation areas in the Salish Sea, Canada. They found it was a reliable, efficient and cost-effective way to monitor near shore marine conservation areas and found it gave comparable results to aerial monitoring, but also allowed for trends in fishing to be assessed. However, Keller *et al*. (2016) found that although shore-based cameras were effective for monitoring changes in recreational fishing effort at an artificial reef off Sydney, Australia, camera images were affected by changes in weather conditions which led to an underestimation of fishing effort by 7.5%. Keller *et al.* (2016) highlighted that validation of images from cameras using field-based observers is needed for this methodology.

Time-lapse cameras and webcams have also been used for a range of studies investigating bait digging and recreational fishing effort (Liley *et al.,* 2012; Hartill *et al.,* 2016). Liley *et al.* (2012) used time-lapse cameras to gain an overview of the intensity based on the frequency of bait digging and number of diggers relative to the area monitored in Holes Bay, Poole Harbour. Using four cameras, almost 43 ha of the shore were within view. Due to the placement of the cameras, the recovery of holes on the shore could also be observed (evidence of holes lasted approximately 7 days) allowing an assessment of bait digging impact. However, only holes within close proximity to the cameras were visible enough to monitor recovery.

A combination of approaches were used by Smallwood *et al.* (2012) to investigate catch rates and fishing effort in Perth, Australia. Aerial surveys counting the number of fishers were combined with 24-hour fixed camera footage and on-site interviews to obtain a clear understanding of the exploitation of nearshore fish stocks. They concluded the methods provided a cost-effective measure of the distribution of shore-based fishing activity over the course of a day.

Both time-lapse cameras and CCTV have also been used to investigate the effects of disturbance from bait digging on bird populations (Fearnley *et al*., 2013, Watson *et al.,* 2017b). Watson *et al.* (2017b) found that waders and gulls moved away from specific areas or even the whole site when collectors were present. As birds are often a designated feature within Marine Protected Areas (MPAs), fixed camera methods could be a useful way to assess wider impacts of bait digging activities.

Overall, the use of fixed cameras is recognised as a cost-effective way of monitoring trends in effort by providing a continuous collection of data. The main benefit of fixed cameras is that they can be used to capture activity over a long period of time, particularly when surveyors are absent. They have the potential to assess the extent and effort of digging based on the location of diggers, number of diggers and time spent on the shore, and to a limited extent can record evidence of damage and rate of subsequent recovery.

Careful consideration would be required regarding the positioning of the cameras to ensure good coverage of the shore. Equally consideration is needed regarding the frequency of photos taken (for time-lapses), the image quality, power source, storage of large amounts of data, and the potential for cameras to be stolen. Much like aerial photography, the images captured would require manual analysis which has the potential to be time intensive, however, time surveying at the location could be greatly reduced. As with aerial photography fixed cameras also provide a bank of images from which data can be collected, verified and archived for future analysis or investigations.

Finally, and importantly, privacy legislations need to be reviewed before the collection of footage of people on the shore (Hartill *et al.,* 2020).

4.4 Existing aerial imagery

Analysis of bait digging extent and intensity can also be achieved using existing ortho-rectified aerial imagery, such as that collected through regional monitoring programmes.

In an assessment of bait digging extent at three sites (Portsmouth Harbour, Langstone Harbour and Chichester Harbour) on the south coast of England, White *et al.* (2022) used aerial photography downloaded from the Channel Coastal Observatory (CCO) to digitise estimations of bait digging impact.

White *et al*. (2022) found that the benefit of using existing aerial imagery was the generally larger extent of shore coverage in comparison to field-based and UAV survey methods. However, assessments were restricted to times, locations and shore extent of the available imagery, which might not always provide the coverage required.

Confidence in any assessment will also be limited by the resolution of the available imagery. In the case of White *et al*. (2022) resolution of the aerial imagery was 10 cm which they concluded was sufficient for the assessment of recent digging, broader and faded digging patterns, and individual pits (~1–2 m across for distinctive pit and mound). However, coarser resolution is unlikely to provide the detail required for confident assessment of bait digging activity. Additionally, as with UAV imagery, analysis of bait digging extent and intensity using existing aerial photography is limited by how long evidence of digging persists on a given shore.

Some existing aerial imagery, such as from the CCO (CCO National Network of Coastal Monitoring) or Environment Agency (Environment Agency Aerial Photography), is freely available to use, making this a cost-effective method of monitoring bait digging activity (where it is possible to do do) as there are no fieldwork or equipment costs. In some cases, there may be a charge for data, however, this is generally less than conducting a UAV survey.

As with UAV methods field-based ground truthing is likely vital for ensuring accuracy of bait digging extent and intensity, and for identifying historic bait digging. The ground-truthing of the aerial images will therefore be a crucial part of photographic analysis and it is likely that some form of field-based survey would be required at each new site.

4.5 Evaluation of monitoring methods

The ability to cover large areas in a relatively short amount of time is hugely beneficial when conducting time sensitive surveys (e.g., around low water and across multiple shores in a season), thus the use of UAVs is recognised as an efficient method for collecting evidence of bait digging across multiple shores around Wales. The standardisation of UAV methods, through pre-programming and pre-planning of flight routes, also allows for an easy comparison to be made between different shores, and the potential variability of bait digging over time can be readily assessed if surveys are repeated on each shore. However, whilst UAVs are a highly efficient survey method, detailed field-based observations would be required to provide a mechanism to ground truth the UAV results in order to confidently assess bait digging extent and intensity which can be costly and time consuming.

The more extensive the initial ground-truthing is, the higher the confidence will be in assessing bait digging evidence and the more detailed the maps of bait digging spatial distribution and intensity will be (Perrins *et al.,* 2020). The method resulting in the highest quality data, giving the most accurate estimate of extent and intensity, would be similar to the method used by Morrell (2007) whereby every hole location is logged using a GPS and later mapped. A similar method could therefore be used to ground truth and evaluate the accuracy of UAV image analysis. However, the costly and time-consuming nature of this method would be a major limitation to the wide use of this approach. With this in mind, it would not be necessary to collect these data across the entire extent of the shore but could be conducted specifically in high, medium and low intensity areas, and also across different sediment/ habitat types.

The collection of high-quality data, through either dedicated transects to ground truth intensity or point locations of dug holes, using GPS could also be compared to the independent identification of bait digging holes and intensity from the UAV photographs in order to more thoroughly investigate the usefulness of the UAV method.

As an alternative field-based approach, walk-over and/or line transect surveys provide a faster method for estimating digging extent and intensity, respectively. For example, using an approach similar to that used in Phase I habitat mapping (Wyn *et al.,* 2000), site walk-over surveys could track the boundaries of bait dug areas using a GPS which could be subsequently mapped to assess digging extent. Line transect surveys could provide counts of holes across a defined area to estimate density and therefore inference of bait digging intensity.

In addition to ground truthing, field-based methods can provide additional information which cannot be assessed with the UAV methodology, such as fine scale temporal (day or tidal cycle) trends in bait digging effort and extent and the age/stage of recovery of different holes on the shore. Overall, it is considered that a combined approach using these methodologies is likely to provide the most robust measure of bait digging extent and intensity on a shore.

In areas where the UAV cannot be flown due to flight restrictions, such as Inland Sea, Cymyran Strait, the collection of site-wide GPS coordinates of bait digging holes (or the use of line transects where time constraints apply) would provide the most robust measure of the extent and intensity of digging on the shore. This could be used to provide a useful comparison to the data collected via field-based surveys conducted where UAVs can be used.

Fixed cameras can be used to gain a cost-effective measure of bait digger effort, such as number of diggers visiting the shore throughout the day or tidal cycle, and overall time on the shore per digger. Data such as this could help towards highlighting the potential variability of bait digging intensity over the long-term. This methodology could also be used to assess the impacts of disturbance from bait digging on bird species. If management measures are implemented to reduce bait digging in protected areas, fixed cameras could also be used to encourage enforcement and to assess compliance (Lancaster *et al.,* 2017; Watson *et al.,* 2017a).

Table 1 Summary of the benefits and limitations of methods to assess the extent and intensity of bait digging activities.

Methods	Benefits	Limitations
Unmanned Aerial Vehicle (UAV)	• Coverage of a large area in a relatively short period of time; • Standardised methodology which can be easily repeated; • Archived data can be easily reviewed and used in subsequent analyses or investigations; • Cost and time-effective method of surveying; and • Allows potential survey of areas which are not accessible on foot.	• Data collection and image quality is heavily dependent on weather, wind and light conditions; • Requires ground truthing from field-based observations to increase accuracy of estimates from obtained UAV imagery; • Collects a single snap shot in time, thus requires repeated surveying to understand long-term bait digging impacts on the shore; • Limited by zones with flying restrictions; • Relatively expensive equipment and staff costs; • High level of staff training required; and • Image processing is time intensive.
Field-based surveys	• Collection of high-quality and accurate data; • Low equipment costs; • Can be used to assess the accuracy of other methods; • Standardised methodology which can be repeated easily; and • Collection of additional data such as targeted species, numbers of diggers and equipment used, site characteristics such as ecology and sediment types to provide a wider context of the effects of bait digging.	• Time and cost intensive on the shore; • Potentially limited coverage across large sites; and • Collects a single snap shot in time, thus requires repeated surveying to understand long-term bait digging impacts on the shore.

Methods	Benefits	Limitations
Fixed cameras	• Ability to collect data on extent and effort over long periods of time; • Standardised methodology which can be repeated easily; • Reduces the need for field-based surveys; • Archived data can be easily reviewed and used in subsequent analyses or investigations; and • Relatively inexpensive.	• Limited coverage particularly across large sites; • Image quality is heavily dependent on weather and light conditions; • Image processing is time intensive; • Mapping of intensity across the shore would be difficult; • Data quality heavily influenced by the positioning of the camera on the shore; • Theft of equipment; • Potential limitations with privacy legislations due to collection of footage of people on the shore; and • Potentially large data storage requirements.
Exiting aerial imagery	• Broad and continuous shore coverage; • No staff survey cost, data processing costs only; and • Minimal equipment and software requirements.	• Do not have control over the location, coverage or survey time; and • Ability to assess bait digging dependent on image resolution.

5 Mapping of Bait Digging Activity

Determining the types of data which can be collected by each survey method and how such outputs can be interpreted and presented is an important consideration at the survey planning stage.

To evaluate the extent and intensity of bait digging Perrins *et al.* (2020) created a virtual raster for each site from the aerial imagery tiles. Ground truthing the raster involved a comparison between the UAV footage and bait digging evidence collected on the shore. This allowed a 'calibration' for each site with which to extrapolate to areas that were not visited by foot. A 100 m grid was applied over each site to ensure all areas were examined for bait digging evidence. The shore was then visually categorised into areas of high, medium and low intensity along with areas where there was no evidence of bait digging.

Perrins *et al.* (2020) found that conventional heat mapping techniques could not be used to show intensity of bait digging. Few individual bait digging holes could be identified and therefore they found maps based on the number of holes could not be generated. Instead, polygons were used to map evidence of bait digging categorised by the intensity of digging, estimated age of the holes and confidence in assessment. White *et al.* (2022) similarly mapped areas of dug sediment as polygons over orthorectified imagery and manually labelled imagery with an assigned confidence.

One of the limitations in the presentation of data using drawn polygons is accurately defining intensity. In this context intensity is a factor of the number of bait dug holes within a given spatial extent. There is therefore a relationship between polygon size and intensity (and to a degree confidence). For example, on the same site one larger polygon could be defined as medium intensity or several smaller polygons as high intensity. These definitions therefore have the potential to influence site vulnerability assessments, such as those undertaken by West *et al*. (2021). If this method is to provide a comparable representation of the data a clearly defined intensity criteria would need to be applied.

In an alternative approach, Birchenough (2013) aimed to quantify the effort of the bait dragging vessels within Poole Harbour using heat maps. To achieve this, positional data were overlaid onto a 250 m^2 grid to determine the number of individual positions within each grid square. A thematic map was then created to show the gradient of effort within the Harbour.

A similar approach to mapping was used by Liley *et al.* (2012) where distribution maps were produced to assess the distribution of wading birds within Poole Harbour. Maps were derived using total counts per 100 m grid cell to derive thematic heat maps of distribution. This enabled simple distribution maps to be plotted, which could be easily compared through time to assess changes in bird distribution in response to bait digging activities.

Field-based studies can produce both polygon and heatmap data, however, the resolution and extent will be determined by the study design. The more extensive the initial field study is, the higher the confidence will be in the evidence of bait digging distribution and intensity.

GPS mapping of the outer extent of bait dug areas can be used to produce polygon maps of extent. These can be supported by on site transects to determine intensity within the polygons, providing higher confidence in the results of the analysis. The method with the potential to result in the most accurate estimate of bait digging extent and intensity, would be similar to the approach used by Morrell (2007) whereby every hole location is logged using a GPS and later mapped. This method would allow highly accurate heat mapping to be undertaken, however, as discussed previously this monitoring method is highly intensive.

The benefit of a heat mapping approach is that the intensity assessment is based on counts and is therefore less subjective. This allows results to be comparable across time and more repeatable between studies. However, depending on the size of the grids used there can be a loss in data resolution compared to polygon mapping, which if done accurately can produce clear areas of extent and intensity. In addition, heat mapping requires high quality imagery to allow identification of individual holes, or if undertaken using field-based methods would require highly intensive monitoring.

It is likely that improvements in technological developments (e.g. machine learning for disturbance detection) will significantly expedite imagery analysis and enable broadscale assessments from aerial imagery (both UAV and existing imagery). This could improve the reliability of the intensity assessments, as all areas will be digitised using the same criteria. However, as with all aerial imagery this will be dependent on image quality and resolution.

6 Recommendations for Future Surveys

The main limitation in Perrins *et al.* (2020) was that the UAV survey was only conducted once on each shore. The more a site is surveyed, the greater the understanding will be regarding the long-term variability in bait digging extent and intensity on the shore. It is therefore recommended that repeat surveys be conducted across the same shores as those studied by Perrins *et al.* (2020).

The surveys undertaken by Perrins *et al.* (2020) were undertaken in winter. Initially, additional surveys could focus on different seasons, for example the summer season where bait collection may increase for the holiday trade. Spatial analysis could then be conducted to investigate the effect of season on bait digging extent and intensity. Surveys during the summer would also allow a further assessment of the usefulness of the UAV methodology under better weather and light conditions.

Routine surveying of the same shores could also provide a fundamentally important and robust baseline with which to compare the effectiveness of management measures. Once management measures are implemented, the changes to bait digger numbers, digging extent or intensity over time can be confidently assessed, for example either with fixed cameras and/or further drone surveys. This would be particularly useful to understand compliance of management measures and for monitoring the potential displacement of diggers if management measures are implemented.

In Perrins *et al.* (2020), the extent and intensity of bait digging was not measured at Inland Sea where the drone was not permitted to fly. It was unclear during field-based surveys whether pitting or depressions in the sediment were a result of bait digging or were of natural origin. At sites such as these, further surveys are needed to understand the number of bait diggers on the shore/ bait digging effort (either with field-based surveys or fixed cameras) to obtain a measure of bait digging effort and the recovery of the holes. Additionally, surveys at Penrhos and Beddmanarch Bay in Perrins *et al.* (2020) resulted in low confidence in the estimate of bait digging extent and intensity due to poor image quality. It is therefore a priority that these areas are re-examined to obtain a more accurate estimate of the impacts of bait digging.

It would also be valuable to know more accurately the speed at which holes decay at different sites and under different sediment/ habitat conditions. To achieve this field-based surveys which repeatedly monitor the same dug holes for recovery would be required. This would be a relatively easy study to undertake across a small number of shores and would allow for more accurate aging of holes and assessment of recovery under different conditions. This would aid in understanding site recovery to bait digging and provide further ground-truthing for UAV data. The Perrins *et al.* (2020) study attempted to assess this, however it only allowed for one repeat visit after several months which did not adequately capture site recovery.

7 Conclusions

Perrins *et al.* (2020) provided a highly informative assessment of the extent and intensity of bait digging on multiple shores in Wales. Using a combination of novel aerial photography, field-based ground-truthing and experimental holes, the study allowed for the potential extent and intensity of bait digging to be assessed.

Whilst the use of a UAV enabled evidence of bait digging activity to be captured across entire shores, it required good weather conditions to coincide with good light conditions and low water. Surveys at Penrhos and Beddmanarch Bay in Perrins *et al*. (2020) resulted in low confidence in the estimate of bait digging extent and intensity due to poor image quality. It is therefore a priority that these areas are re-examined to obtain a more accurate estimate of the impacts of bait digging.

A significant level of ground truthing through field-based observations was also required to ensure accuracy in the UAV assessment. The field-based survey identified both key areas of bait digging prior to image analysis and any patterns or artefacts in the sediment to be highlighted which may look similar to historic bait digging. Without field-based ground truthing historic bait digging was likely very difficult to determine using aerial photography. The ground-truthing of the aerial images was vital to ensure higher accuracy of bait digging extent and intensity estimates. It is therefore likely that the field-based ground truthing will always be required to some degree and would have to be done at each new site.

Analysis of bait digging extent and intensity by aerial photography are limited by how long evidence of digging persists on a given shore. However, the field-based experimental holes dug for examining sediment recovery in Perrins *et al*. (2020) were useful to determine the uncertainty of the aerial photography by highlighting sites where bait digging extent and intensity were likely underestimated due to short-term recovery. Ultimately, the field-based survey and experimental holes highlighted that a combined approach is necessary to ensure a robust evaluation of bait digging impact when using aerial photography.

All survey methodologies reviewed in this report have benefits and limitation associated with them and as such a combined survey approach, extending on the approach undertaken in Perrins *et al.* (2020), will give the most robust quantification of bait digging extent and intensity. The use of UAVs (or existing aerial imagery), in combination with field-based survey methods provides the best combination of cost and time effective monitoring whilst maintaining a high level of accuracy for quantifying digging extent, intensity and effort. The use of fixed cameras could also provide a mechanism for providing greater temporal data coverage with the potential to capture bait digging in progress. This technique may also encourage enforcement and provide a means of monitoring compliance of any bait digging management measures.

Perrins *et al.* (2020) provided an initial evaluation of bait digging extent and intensity on Welsh shores, however it only captured the impact of bait digging during a single snapshot in time. Bait digging activities are known to be variable over time, particularly between seasons. Therefore, repeated surveying of the same shores from Perrins *et al.* (2020) would highlight potential long-term variability of bait digging on the shore and provide a more in depth understanding of bait digging with which to base management measures.

Further research to thoroughly investigate the usefulness of the UAV method is recommended. This could involve field-based collection of high-quality data using GPS, which could be compared to the independent identification of bait digging holes and intensity from the UAV photographs.

8 Abbreviations

CAA	Civil Aviation Authority
CCO	Channel Coast Observatory
CCTV	Closed-Circuit Television
CCW	Countryside Council for Wales
DMARES	Drone and Model Aircraft Registration
GPS	Global Positioning System
ID	Identification
MPA	Marine Protected Area
NRW	Natural Resources Wales
RAF	Royal Airforce
SPA	Special Protection Area
UAV	Unmanned Aerial Vehicle
UK	United Kingdom

9 References

Birchenough, S. 2013. Impact of bait collecting in Poole Harbour and other estuaries within the Southern IFCA District. A report for Southern Inshore Fisheries and Conservation Authority. Project Fes 286.

Cryer M, Whittle G.N, and Williams R. 1987. The impact of bait collection by anglers on marine intertidal invertebrates. *Biological Conservation.* 42 (2), 83-93.

Fearnley H, Cruickshanks K, Lake S, and Liley D. 2013. The effect of bait harvesting on bird distribution and foraging behaviour in Poole Harbour SPA. Unpublished report by Footprint Ecology for Natural England.

Fowler S.L. 1999. Guidelines for managing the collection of bait and other shoreline animals within UK European marine sites. English Nature (UK Marine SACs Project). Available from: http://ukmpa.marinebiodiversity.org/pdf/Activities/bait.pdf [Accessed August 2021].

Hartill B.W, Payne G.W, Rush N, and Bian R. 2016. Bridging the temporal gap: continuous and cost-effective monitoring of dynamic recreational fisheries by web cameras and creel surveys. *Fisheries Research.* 183, 488-497.

Hartill B.W, Taylor, S.M, Keller K, and Weltersbach M.S. 2020. Digital camera monitoring of recreational fishing effort: applications and challenges. *Fish and Fisheries.* 21 (1), 204-215.

Keller K, Steffe A.S, Lowry M, Murphy J.J, and Suthers I.M. 2016. Monitoring boat-based recreational fishing effort at a nearshore artificial reef with a shore-based camera. *Fisheries Research.* 181, 84-92.

Lancaster D, Dearden P, Haggarty D.R, Volpe J.P, and Ban N.C. 2017. Effectiveness of shore-based remote camera monitoring for quantifying recreational fisher compliance in marine conservation areas. *Aquatic Conservation: Marine and Freshwater Ecosystems.* 27 (4), 804-813.

Liley D, Cruickshanks K, Fearnley, H, and Lake S. 2012 The effect of bait collection on waterfowl foraging behaviour in Holes Bay, Poole Harbour. Report for Natural England. Footprint Ecology Ltd., Wareham, Dorset.

McEvoy J.F, Hall G.P, and McDonald P.G. 2016. Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: disturbance effects and species recognition. *PeerJ.* 4, e1831.

Morrell S.L. 2007. Assessment of bait collection activity, impact and bait resources within Milford Haven Waterway. CCW Research Contract Technical Specification Contract Number: UC28-B107. Countryside Council for Wales.

Perrins J, Lush M, Taylor T, Holt R, and Bunker F. 2020. Investigating the location and intensity of bait digging in Wales. NRW Evidence Report Series Report No: 449, 170. NRW: Bangor.

Smallwood C.B, Pollock K.H, Wise B.S, Hall N.G, and Gaughan D.J. 2012. Expanding aerial–roving surveys to include counts of shore-based recreational fishers from remotely operated cameras: benefits, limitations, and cost effectiveness. *North American Journal of Fisheries Management.* 32 (6), 1265-1276.

Sypitkowski E, Bohlen C, and Ambrose Jr W.G. 2010. Estimating the frequency and extent of bloodworm digging in Maine from aerial photography. *Fisheries Research.* 101 (1-2), 87-93.

Watson G.J, Murray J.M, Schaefer M and Bonner A. 2017a. Bait worms: a valuable and important fishery with implications for fisheries and conservation management. *Fish and Fisheries*. 18 (2), 374-388.

Watson G.J, Murray J.M, Schaefer M, Bonner A, and Gillingham M. 2017b. Assessing the impacts of bait collection on inter-tidal sediment and the associated macrofaunal and bird communities: The importance of appropriate spatial scales. *Marine Environmental Research*. 130,122-133.

West V, Robbins K, Frost N, Hull, S. 2021. Bait Digging Management Options. Report by ABPmer for NRW. Report No R3772.

White S.M, Schaefer M, Barfield P, Cantrell R, and Watson G.J. 2022. Cost benefit analysis of survey methods for assessing intertidal sediment disturbance: A bait collection case study. *Journal of Environmental Management.* 306. 114386.

Wyn G, Brazier P, McMath M, and Jones M. 2000. Handbook for marine intertidal Phase 1 biotope mapping survey. Countryside Council for Wales. pp114.

10 Appendices

10.1 Data Archive Appendix

No data outputs were produced as part of this project.