Evaluation of Welsh coastal shingle and appropriate sources of nourishment material

Report No: 756

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Crynodeb Gweithredol

Cydnabyddir yn gyffredinol bod traethau graean bras a choblau yn ffyrdd cost-effeithiol a chynaliadwy o amddiffyn yr arfordir, gan wasgaru llawer iawn o ynni'r tonnau yn ystod stormydd eithafol. Yn yr adroddiad hwn ac yn ehangach, cyfeirir yn aml at draethau o'r fath fel rhai sydd â chyfansoddiad 'graean bras' neu 'gerrig mân' oherwydd ystod maint y graean, o gerrig crynion bach i goblau mwy. Mae gan gynlluniau adfer traethau y potensial i gynnal a gwella'r amddiffyniad arfordirol a ddarperir gan draethau graean bras. Mae hyn yn fwy cynaliadwy yn amgylcheddol o gymharu â dulliau 'traddodiadol' (e.e., waliau môr a strwythurau mawr eraill). Dylid cynnal gwaith adfer ar draethau graean bras gan ddefnyddio deunydd crwn sydd naill ai o faint tebyg, neu ychydig yn fwy bras na'r graean bras sydd yno ar hyn o bryd. Gall hyn wneud y gwaith o ddod o hyd i ddeunydd addas yn her sylweddol i awdurdodau rheoli arfordirol.

Mae'r astudiaeth bresennol yn nodweddu dosbarthiad maint gwaddod 5 traeth graean bras ledled Cymru. Nodwyd y safleoedd hyn gan CNC fel ymgeiswyr posibl ar gyfer adfer traethau sy'n gynrychioliadol o gwmpas daearyddol yr arfordir.

Ym mhob safle astudio, cymhwyswyd dull maint graean digidol (DGS) ar gyfer nifer o ffotograffau o arwyneb y safleoedd er mwyn darparu nifer o baramedrau allweddol ar gyfer maint y graean, gan gynnwys:

- Maint graean cymedrig.
- Didoli maint graean: gwyriad safonol rhifyddol o feintiau graean.
- Sgiwedd maint graean.
- Cwrtosis maint graean.
- Canraddau dosbarthiad maint graean cronnus (% yn llai na).
- Amledd maint graean: yr amleddau wedi'u normaleiddio sy'n gysylltiedig â 'biniau maint graean'.

Casglwyd samplau ffisegol ym mhob un o'r safleoedd er mwyn darparu asesiad o'u mwynoleg. Mae angen mwynoleg fel y gall rheolwyr arfordirol sicrhau bod unrhyw ddeunydd a ddefnyddir i adfer y safleoedd yn ddigon caled fel nad yw'n erydu gyda symudiadau'r tonnau.Defnyddiwyd y British Geological Survey (BGS) Directory of Mines and Quarries (2020) i nodi ffynonellau graean ar y tir yng Nghymru a fyddai'n addas ar gyfer adfer y traethau ym mhob un o'r safleoedd graean. Chwarel Cefn Graianog yw'r ffynhonnell fwyaf addas o ddeunydd ar gyfer y safleoedd sydd ar hyd arfordir y gogledd a'r gorllewin. Prin yw'r ffynonellau graean a choblau ar y tir ar gyfer y safleoedd ar arfordir y de. Fodd bynnag, gallai cael gafael ar ddeunydd o sawl chwarel fod yn un ateb. Fel arall, gall chwareli creigiau onglog gynnig dewis arall addas.

Dylid defnyddio canlyniadau'r astudiaeth hon yn bennaf i hysbysu awdurdodau rheoli arfordirol o feintiau'r deunyddiau sydd eu hangen i adfer pob un o'r 5 safle graean. Yn ogystal, mae'r canfyddiadau'n tynnu sylw at y ffaith y gallai cael gafael ar ddeunydd o fewn y pellter cludiant delfrydol yn economaidd ar gyfer safleoedd graean bras yn y de fod yn her o safbwynt ymdrechion adfer yn y dyfodol.

Executive summary

Gravel and cobble beaches are widely regarded as being cost-effective and sustainable forms of coastal defence, dissipating large amounts of wave energy during extreme storms. Within this report and more widely such beaches are often referred to as having a ‘shingle’ composition due to the range of grain sizes from small pebbles to larger cobbles. Beach nourishment has the potential to maintain and enhance the coastal protection provided by gravel beaches. This is more environmentally sustainable compared to ‘traditional’ approaches (e.g., sea walls and other large structures). Nourishment on shingle beaches should be undertaken using rounded material that is either of similar size, or slightly coarser than the existing shingle. This can make sourcing suitable material a significant challenge for coastal management authorities.

The present study provides a characterisation of the sediment size distribution of 5 shingle beaches located around Wales. These sites were identified by NRW as potential candidates for beach nourishment that provide a representative geographic spread of the coastline.

At each study site, a digital grain size (DGS) approach was applied to multiple surface photographs of the site to provide a number of key grain-size parameters, including:

- Mean grain size.
- Grain size sorting: arithmetic standard deviation of grain sizes.
- Grain size skewness.
- Grain size kurtosis.
- Percentiles of the cumulative (% less than) grain size distribution.
- Grain size frequencies: the normalised frequencies associated with 'grain size bins'.

Physical samples were collected at each of the sites in order to provide an assessment of their minerology. Minerology is required so coastal managers can ensure any material used to nourish the sites is of sufficient hardness that it does not abrade away during wave action.

The British Geological Survey (BGS) Directory of Mines and Quarries (2020) was used to identify land-based sources of gravel in Wales that would be suitable for nourishment at each of the gravel sites. The Cefn Graianog Quarry is the most suitable source of material for the sites located along the north and west coastline of Wales. Land-based sources of gravel and cobbles for the sites on the south coastline of Wales are limited. However, sourcing material from multiple quarries could provide a solution. Alternatively, angular rock quarries may provide a suitable alternative.

The results of this study should primarily be used to inform coastal management authorities on the sizes of material required to nourish each of the 5 gravel sites. Additionally, findings highlight that sourcing material within the ideal economic transport distance for coarse gravel sites in the south of Wales may present a challenge for future nourishment efforts.

1. Introduction

1.1 Gravel beaches and beach nourishment

The coastal zone is one of the most heavily populated areas worldwide, containing an abundance of settlements, critical infrastructure, and rich and diverse ecosytems (Vousdoukas, et al., 2020). Consequently, as climate change drives sea-level rise and potentially enhanced storminess, it is becoming more important than ever that coastal management practices and policy are informed by robust scientific evidence (Masselink, McCall, Poate, & van Geer, 2014). This is especially true for highly dynamic coastal environments such as gravel beach (and barrier) systems (Buscombe & Masselink, 2006), which can experience rapid and large-scale changes to their morphology under extreme forcing conditions (Ruiz de Alegria-Arzaburu & Masselink, 2010; Scott, et al., 2016).

Gravel beaches develop where there is an abundant supply of gravel-sized material (diameter (D) > 2 mm) within the coastal zone. The term gravel can encompass a range of sediment classes including pebbles (D = 4 to 64 mm) and cobbles (D = 64 to 256 mm). Furthermore, the term ‘shingle’ is often used to describe gravel/cobble beaches. These beaches are common along high-latitude, formerly (peri-) glaciated coastlines (Northern Europe, Japan, USA), or in locations where riverine output/cliff erosion has resulted in large quantities of sediment being made available (Phillips, Brown, & Plater, 2020; Ruiz de Alegria-Arzaburu & Masselink, 2010). Gravel beaches are widely regarded as being extremely cost-effective and sustainable forms of coastal defence, displaying a high natural ability to dissipate large amounts of wave energy. The presence of gravel beaches can help to reduce the impacts that extreme storms will have on coastal communities’ infrastructure, and coastal habitats of high conservation value (Aminti, Cipriani, & Pranzini, 2003; Pye & Blott, Progressive Breakdown of a Gravel-Dominated Coastal Barrier, Dunwich-Walberswick, Suffolk, U.K.: Processes and Implications , 2009). However, like much of the coastline coastal erosion is evident along many gravel beaches in the UK, with regular breaching and storm damage occurring at many sites. This leads to a reduction in the level of coastal protection gravel beaches are able to provide to coastal communities. Consequently, large coastal engineering structures are extensively used, at great financial and environmental expense, to maintain and enhance their coastal protection ability (Masselink, McCall, Poate, & van Geer, 2014).

Jennings and Schulmeister (2002) provide a classification scheme for gravel beaches from field-based observations. Their study divides gravel beaches into three main types:

1. Pure gravel beaches (PG): Consisting of steep profile slopes ($\tan\beta$) = 0.08–0.24, with average sediment size decreasing from the storm berm down to the swash zone.

2. Mixed sand–gravel (MSG): Consisting of moderate profile slopes ($\tan\beta$) = 0.04 –0.13, subdivided into beaches with (a) largely intermixed sand and gravel and (b) a higher degree of sorting of sand and gravel in a cross-shore direction.

3. Composite gravel and sand beaches (CGS): Consisting of a steep gravel berm with a low-angle intertidal foreshore and well-sorted sand and gravel in the cross-shore direction. Slope values are comparable to that of MSG beaches. Composite beaches are common in Wales.

In Wales, gravel beaches are acknowledged as a vital natural, social, and economic resource, especially from a flood and coastal erosion risk management (FCERM) point of view (Pye & Blott, 2009). As it becomes more widely recognised that 'traditional' approaches for managing coastal erosion and flood risk (e.g., sea walls and other large structures) are often not environmentally or financially sustainable, coastal managers are looking to use beach nourishment to enhance the long-term resilience of gravel coastlines. Beach nourishment has the potential to offer a great alternative to managing coastal risk that works more with natural coastal processes rather than against them, leading to less environmentally and ecologically damaging consequences. However, for beach nourishment to be successfully implemented on a wider scale in Wales, certain practical issues need to be addressed.

One key issue is the availability of appropriate material; ideally, beach nourishment should be undertaken using gravel or cobble sized material that is of similar size and shape, or slightly coarser than the existing material (Pye & Blott, 2018). This ensures that the material is large enough that it remains on the beach and works within the existing processes, but not so large that it drastically alters the natural state of the system. The material should also be similar in its mineralogical properties, primarily to ensure it is of sufficient hardness so that it does not abrade away (Pye & Blott, 2018). However, finding material that is of suitable grade and composition within an economic transport distance is often challenging (Pye & Blott, 2018).

To determine the material required for nourishment, grain size distribution analysis must be conducted. Traditional methods for obtaining grain size measurements are hampered by: the intrusiveness and time consuming nature of sediment sampling; the expense of subsequent laboratory analysis; and, in some cases, the logistical costs of retrieval and transport (Prodger, Russel, & Davidson, 2017). This is especially true for gravel sites, which display a wide variety of possible sedimentological assemblages, with sediment sizes ranging over three orders of magnitude from sand to gravels and boulders (Horn & Walton, 2007). Consequently, sediment is often too large to physically collect a representative sample, and taking individual measurements using callipers would be too time consuming and costly to justify. Additionally, in Wales, many gravel beaches are designated sites (e.g. SSSI) which means that removal of sufficient sediment for particle size analysis is not possible or would require licences, the attainment of which is not compatible with a short project.

In order to improve the spatial resolution and reduce the expenses of sediment studies, traditional methods of physical collection and analysis of sediment samples are being replaced by advancements in semi-autonomous image processing techniques. These approaches are designed to extract a grain-size and sorting values from digital photographs of the beach surface (Prodger, Russel, & Davidson, 2017); known as digital grain-size (DGS) analysis. Buscombe (2013) developed the first method of DGS which is completely transferrable, unmodified, without calibration, for both consolidated and unconsolidated sediment. The success of this approach is, in part, due to it quantifying both the spectral (backlight intensity of pixels) and spatial (location and size) information from the sediment image simultaneously.

Adopting the DGS analysis method developed by Buscombe (2013), this advisory report, commissioned by Natural Resources Wales (NRW) and produced by Coastal Marine Applied Research (CMAR) aims to investigate five key gravel sites around the coastline of Wales and provide a characterisation of their sediment grain-size distributions. The purpose of this work is to firstly provide coastal managers with the necessary data to inform future beach nourishment should it be deemed necessary and appropriate to do so, and secondly to identify possible land-based sources of material in Wales that could be used to nourish the gravel sites.

1.2 Report structure

The structure of this report is summarised below:

Section 2: Introduces the five study sites identified by NRW as potential candidates for beach nourishment.

Section 3: Presents the methodology used for the DGS analysis and mineralogical assessment of the study sites.

Section 4: Presents the results of the DGS analysis and mineralogical assessment.

Section 5: Identifies potential land-based sources of material that could be used to nourish each of the study sites.

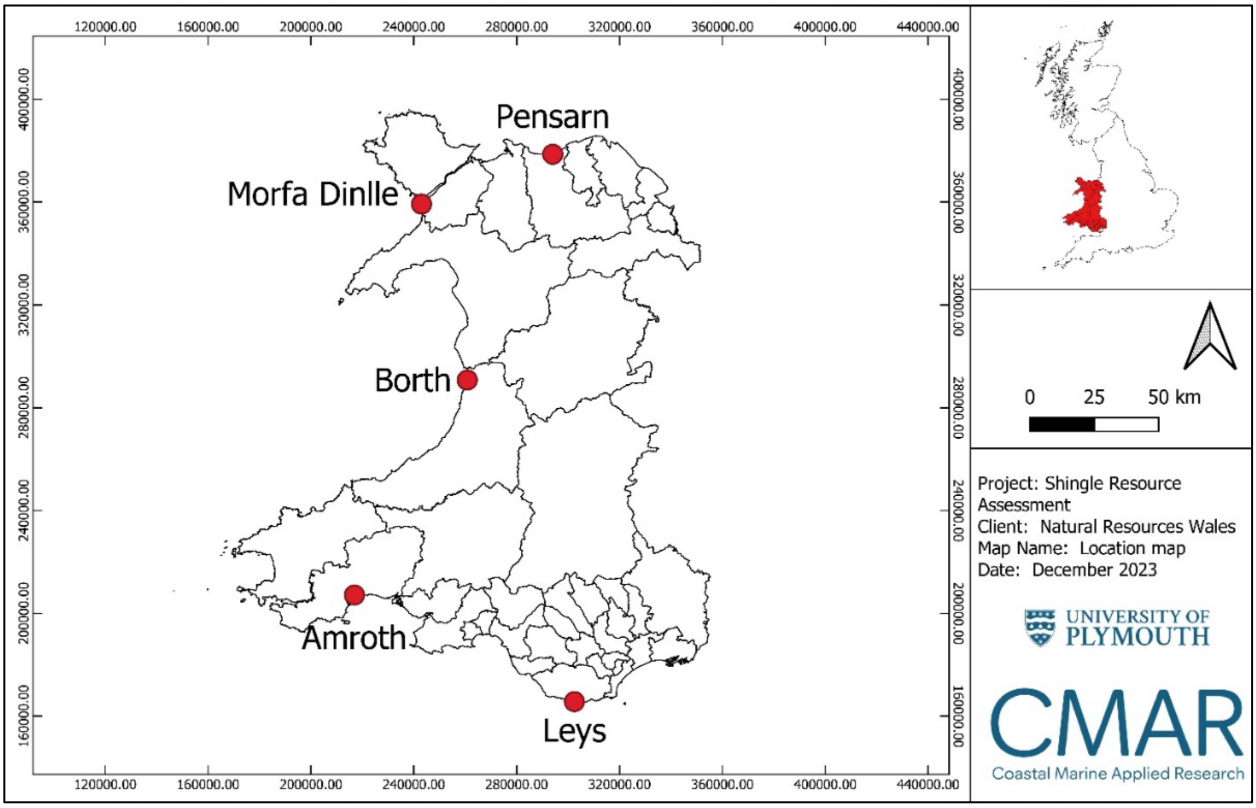

Figure 1: Location map of the five gravel beaches visited in this study. Sites have been identified by Natural Resources Wales (NRW) as potential candidates for beach nourishment.

2. Study sites

The present study focuses on five gravel beaches located around the Welsh coast (Figure *1*). These sites were determined based on the Database of Welsh shingle beaches in Pye and Blott (2018). The database was filtered for sites which had both high flood and coastal erosion risk management (FCERM) importance and marked as high importance for another category in the database (e.g. conservation or recreation). This subset was ranked on area of gravel and then sites selected in order of descending size to ensure a good geographic spread.

The first site, Pensarn, is located on the north coast of Wales and is exposed to locally derived wind-waves from the northwest, with summer and winter significant wave height (*Hs*) of <1 m. The second and third sites, Morfa Dinlle and Borth, are located on the west coast of Wales and are exposed to both Atlantic derived storm (swell) waves and locally derived wind-waves, with summer and winter mean *Hs* of around 1 m and 1.5 m, respectively. The fourth and fifth sites, Amroth and Leys, are located on the south coast of Wales, and are mostly dominated by Atlantic derived storm waves, with summer and winter mean *Hs* of around 1 m and 1.5 m, respectively (Scott, et al., 2021).

2.1 Pensarn

The site at Pensarn (Figure 2 & Figure 3) can be characterised as a composite gravel beach type, consisting of a steep gravel berm and a lower-angle wide sandy intertidal zone. The site is part of a 2800 m stretch of gravel and sand coastline with an average cross-shore width of 310 m (measured from storm berm to mean low water spring (MLWS) level). The upper gravel section of the profile has an average crest height of 6.26 m, an average width of 51 m (measured from the storm berm to the break point in the profile) and an average slope angle of tanβ = 0.11.

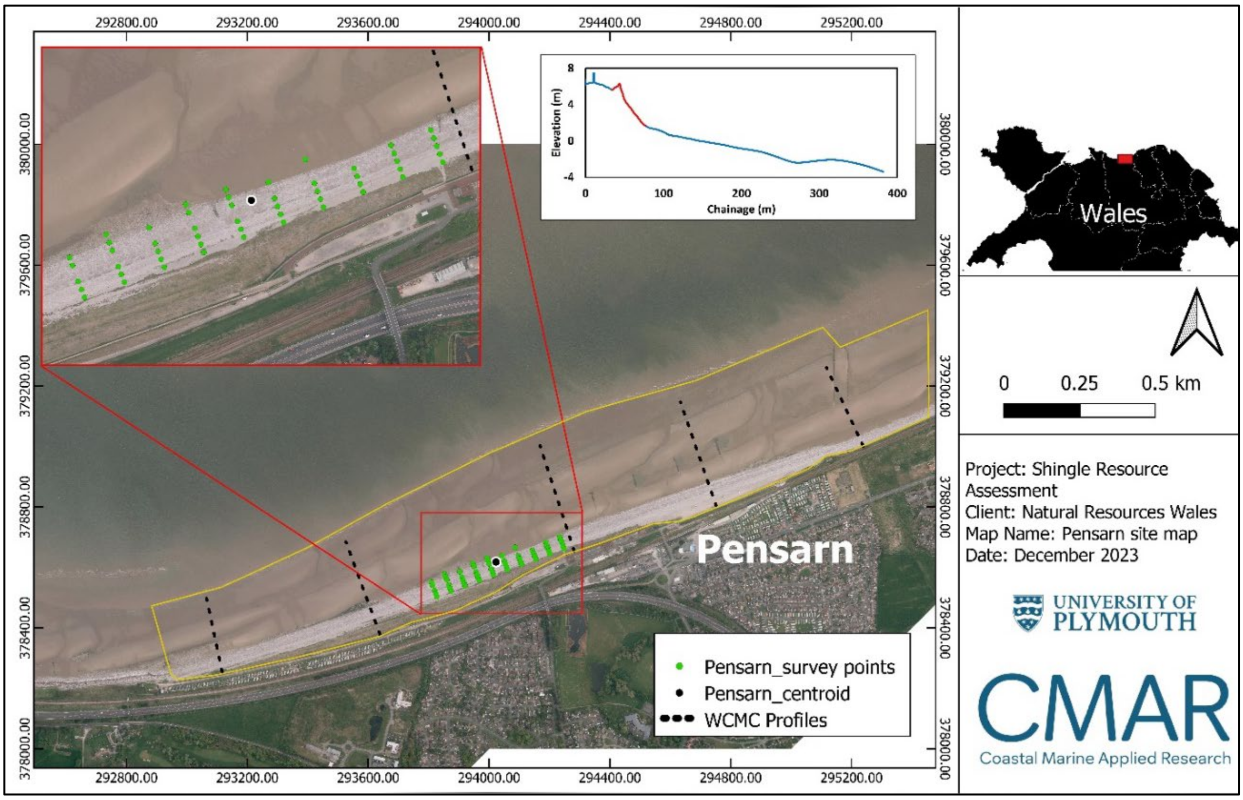

Figure 2: Site map of Pensarn beach. Yellow polygon indicates the extent of the composite gravel and sand system, with sea defences at either end of the site. Survey area is highlighted by red zoom box, with green points indicating each of the 52 digital sediment samples collected. RTK-GPS profiles (sourced from Welsh Coastal Monitoring Centre (WCMC; https://www.wcmc.wales/) used for average height and slope calculation are shown (black dashed line). Plot of profile 11a2.3_063 is shown (red highlights the gravel section of the profile). Aerial images courtesy of the WCMC (https://www.wcmc.wales/).

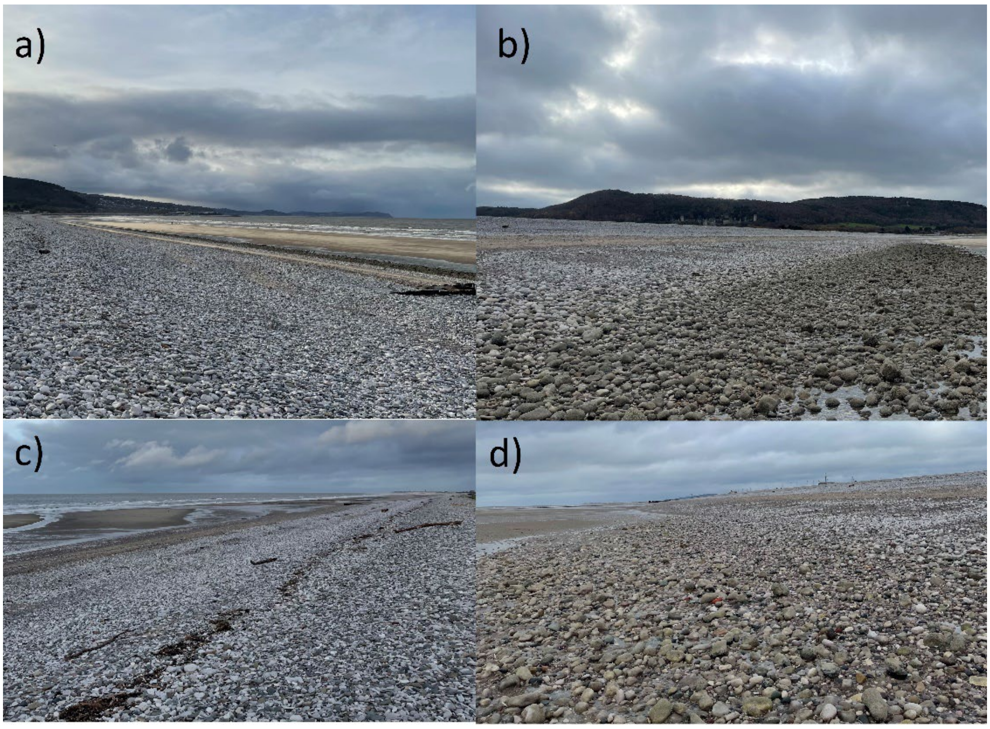

Figure 3: Pensarn site photographs showing oblique alongshore perspectives. Photos a) and b) are taken looking westward and photos c) and d) are taken looking eastward.

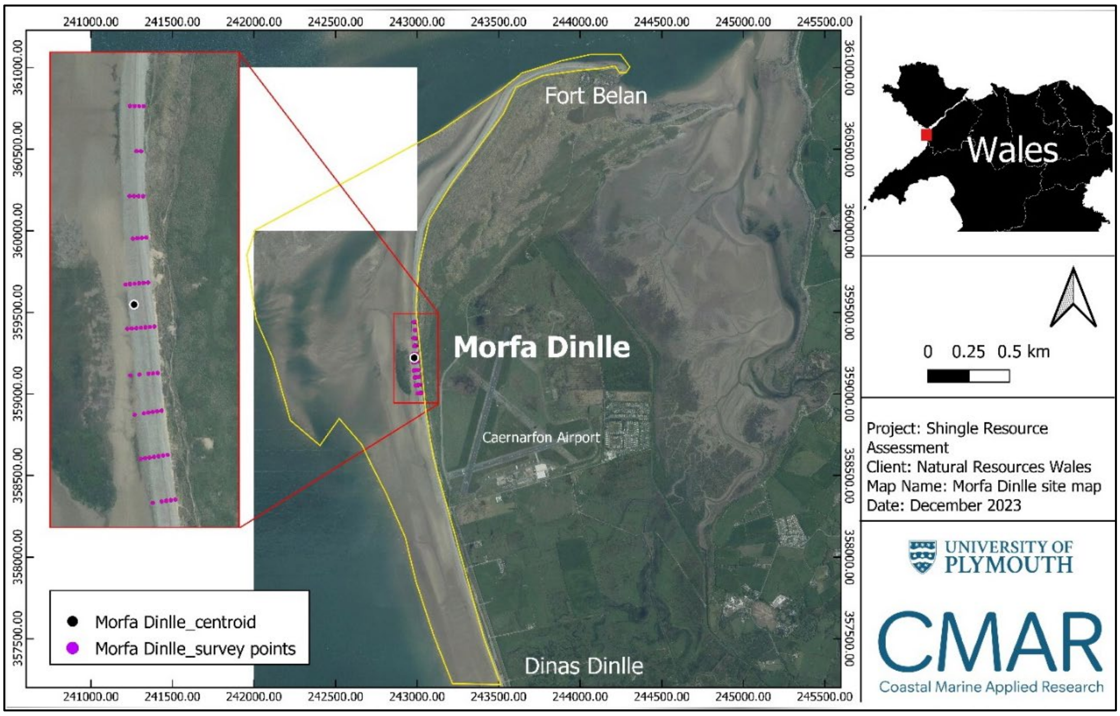

Figure 4: Morfa Dinlle site map. Yellow polygon indicates the extent of the composite gravel and sand spit system. Survey area is highlighted by zoom box, with purple points indicating each of the 50 digital sediment samples collected. No RTK-GPS profiles were available from the WCMC for this study site. Aerial images © Bluesky International Limited and Getmapping 2024

Figure 5: Morfa Dinlle site photographs showing oblique alongshore perspectives. Photos a) and b) were taken looking northward direction and photos c) and d) were taken looking south.

2.2 Morfa Dinlle

The study site Morfa Dinlle (Figure *4* and Figure *5*) is part of a 4880 m long composite gravel spit system, stretching from Dinas Dinlle beach in the south to Fort Belan in the north. The site is backed by a small dune system with an active airport directly behind. The upper gravel section of the beach has an average cross-shore width of 48 m.

2.3 Borth Sands

The study site at Borth (Figure *6* & Figure *7*) can be characterised as a composite type gravel beach, and is part of a 6340 m long stretch of gravel and sand coastline that extends from the cliffs at Upper Borth to a sand dune spit system known as Ynyslas Sand Dunes. The average cross-shore width is 186 m (measured from storm berm to MLWS). The upper gravel section of the profile has an average crest height of 5.1 m, an average width of 42.4 m (measured from the storm berm to the break point in the profile) and an average slope angle of tanβ = 0.10.

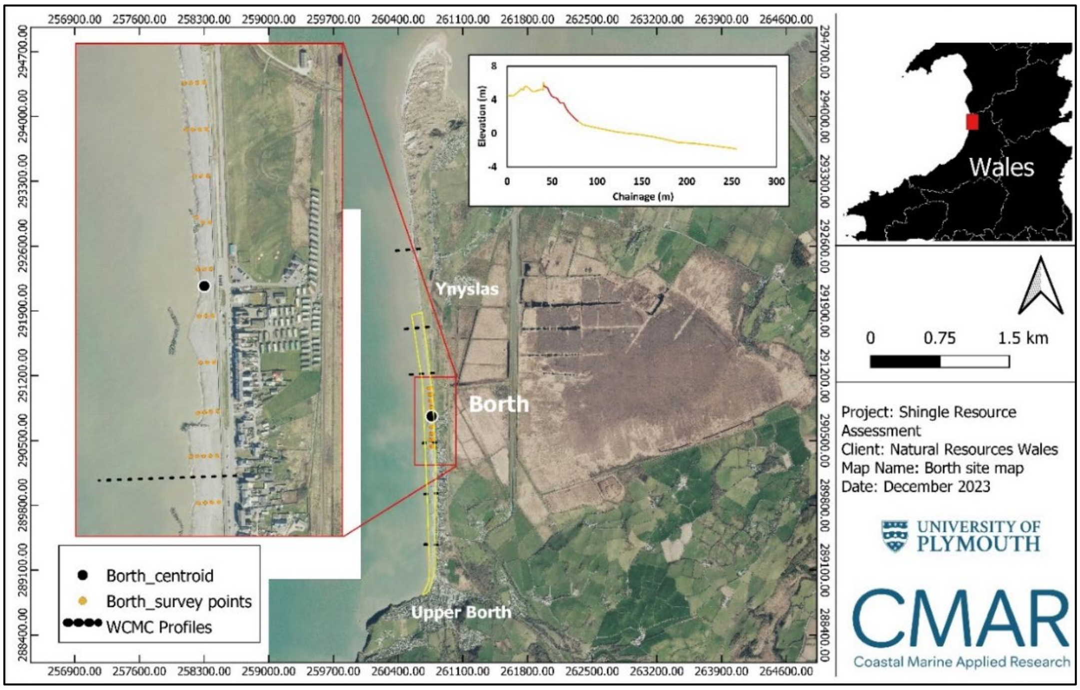

Figure 6: Borth site map. Yellow polygon indicates the extent of Borth Sands, a composite gravel and sand system. Survey area is highlighted by red zoom box, with orange points indicating each of the 36 digital sediment samples collected. RTK-GPS profiles (courtesy of WCMC; https://www.wcmc.wales/) used for average height and slope calculation are shown (black dashed line). Plot for profile 9a10.3_010 is shown (red highlights the gravel section of the profile). Aerial images © Bluesky International Limited and Getmapping 2024.

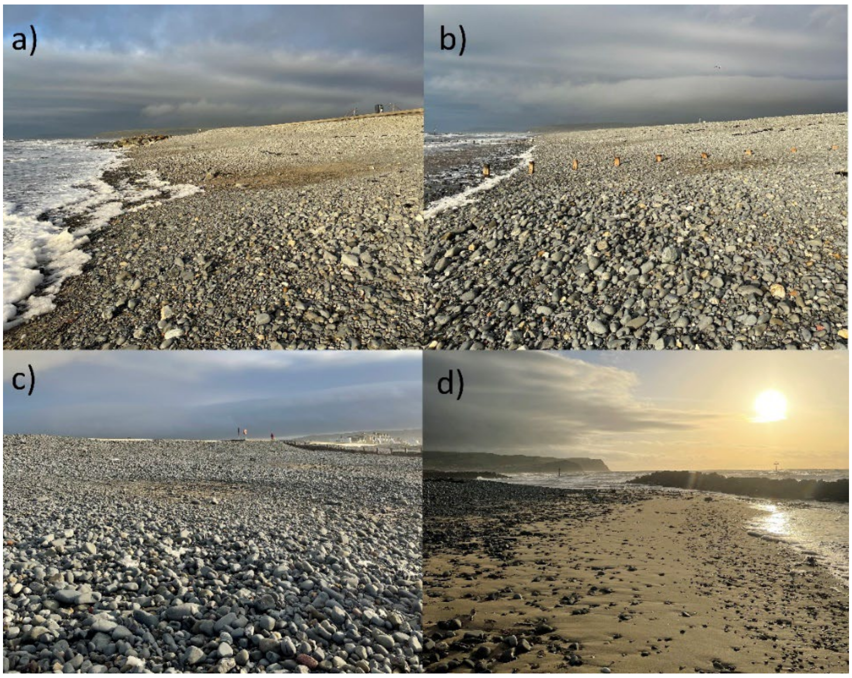

Figure 7: Borth site photographs showing oblique alongshore perspectives. Photos 1a and 1b were taken looking northward and photos 2a and 2b were taken looking south.

2.4 Amroth Beach

The Amroth study site (Figure *8* & Figure *9*) can be characterised as a composite gravel beach, with a very steep upper gravel berm and a wide low-angle sandy intertidal zone. The site has an alongshore length of 1460 m and an average cross-shore width of 331 m (measured from storm berm to MLWS). The upper gravel section of the profile has an average crest height of 6.0 m, an average width of 27 m (measured from the storm berm to the break point in the profile) and an average slope angle of tanβ = 0.17. It should be noted several wooden and rock groynes are present along the site.

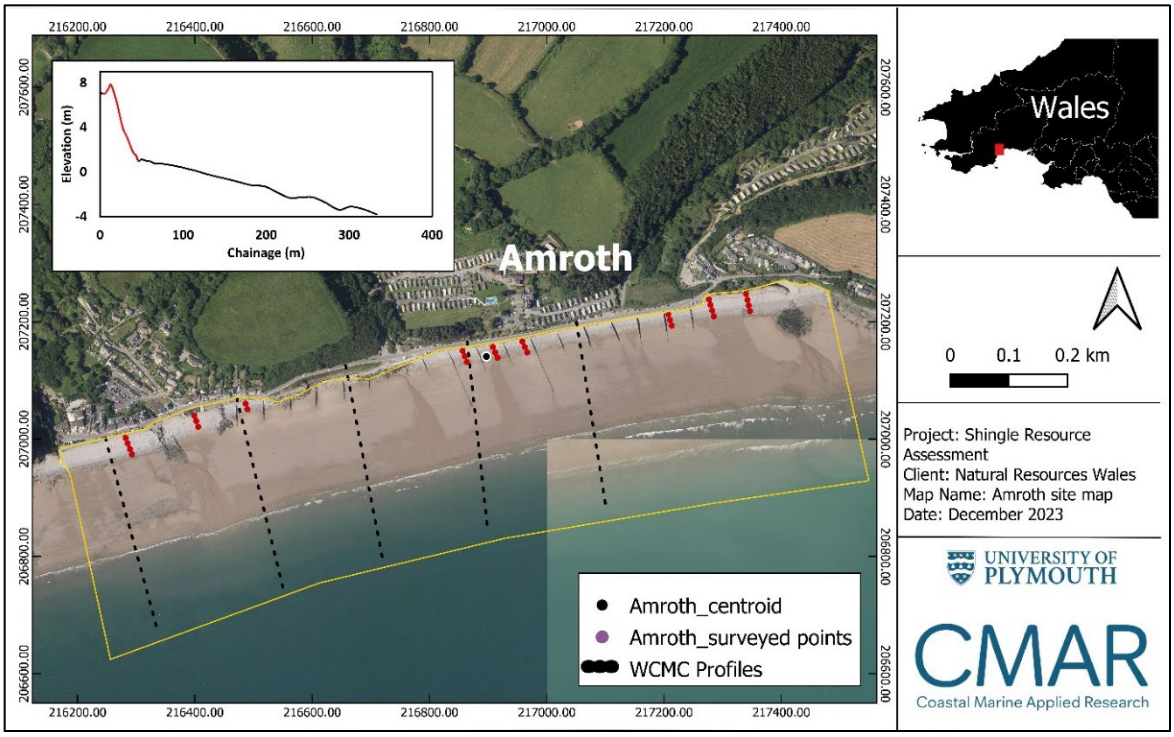

Figure 8: Amroth site map. Yellow polygon indicates the extent of Amroth beach, a composite gravel and sand system. Red points indicate each of the 30 digital sediment samples collected. RTK-GPS profiles (sourced from WCMC: https://www.wcmc.wales/) used for average height and slope calculation are shown (black dashed line). Plot for profile 8c16.2_020 is shown (red highlights the gravel section of the profile). Aerial images © Bluesky International Limited and Getmapping 2024.

Figure 9: Amroth site photographs showing oblique alongshore perspectives. Photos a) and b) were taken at the west end of the site looking eastward and photos c) and d) were taken at the east end of the site looking westward.

2.5 The Leys

The Leys study site (Figure *10* & Figure *11*) can be broadly characterised as a composite gravel beach, with a steeper upper gravel berm and a lower angle sandy intertidal zone. However, unlike the other study sites, Leys is situated on a wide rock/boulder platform that extends out to MLWS level. The site has an alongshore length of around 1600 m and an average cross-shore width of 486 m (measured from storm berm to MLWS). The upper gravel beach has an average crest height of 7.5 m, an average width of 34.9 m (measured from the storm berm to the break point in the profile) and an average slope angle of tanβ = 0.14. It should be noted concrete groynes are present on the southern side of the site.

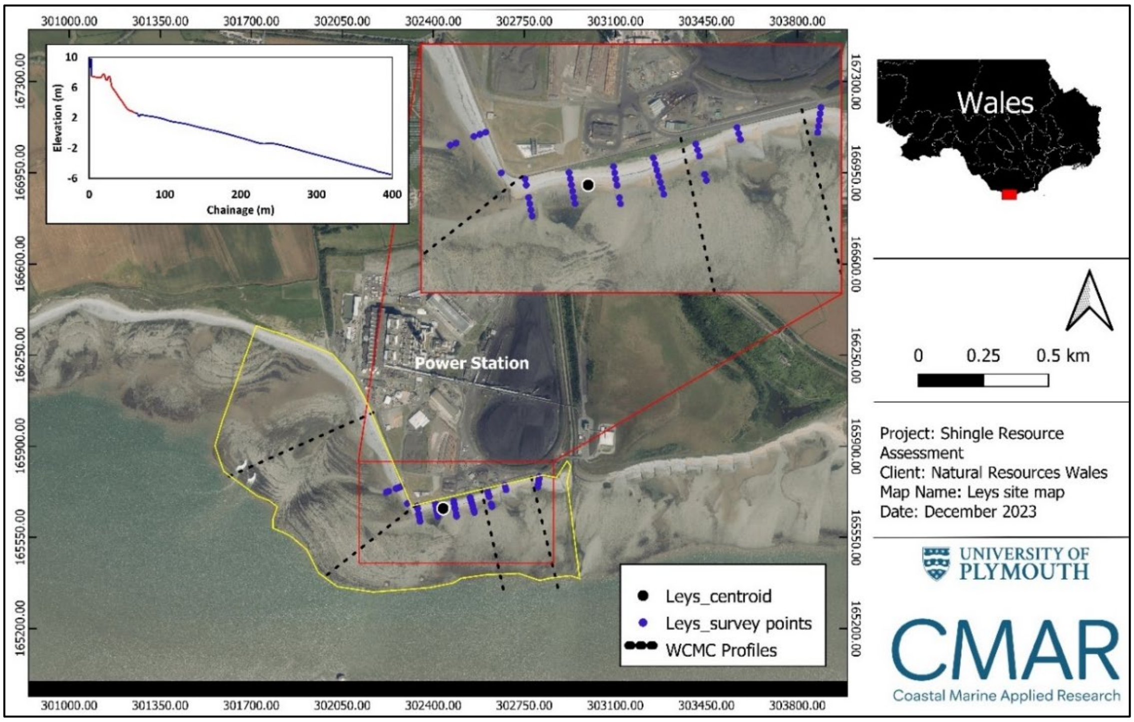

Figure 10: Leys site map. Yellow polygon indicates the extent of "The Leys" beach. Survey area is highlighted by red zoom box, with blue points indicating each of the 46 digital sediment samples collected. RTK-GPS profiles (sourced from WCMC: https://www.wcmc.wales/) used for average height and slope calculation are also shown (black dashed line). Plot for profile 8b4.1_032 is shown (red highlights the upper gravel section of the profile). Aerial images © Bluesky International Limited and Getmapping 2024.

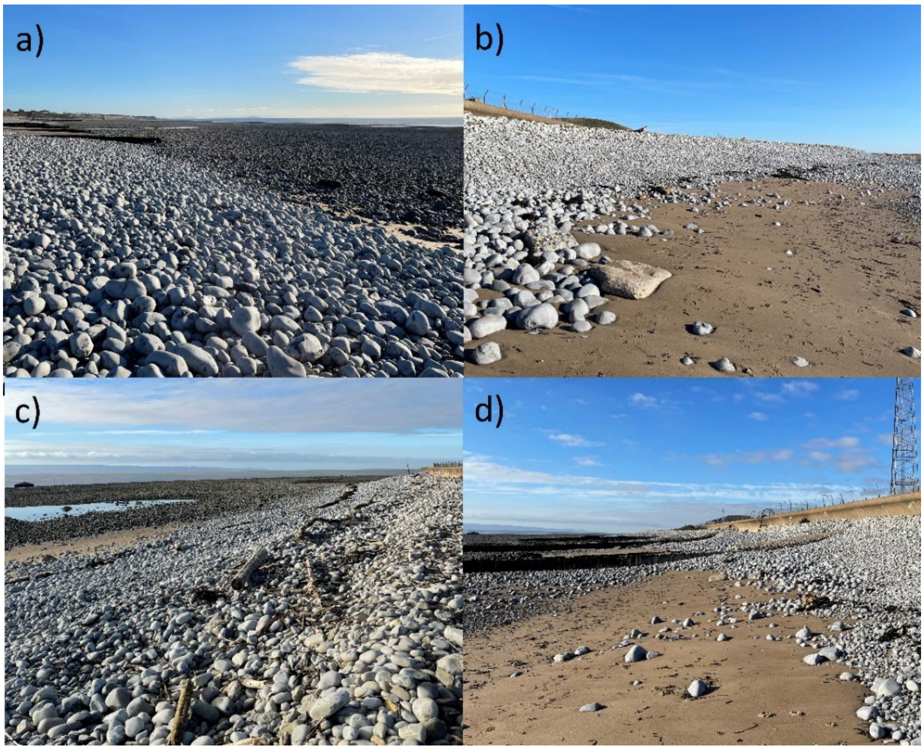

Figure 11: Leys site photographs showing oblique alongshore perspectives. Photos a) and b) were taken looking eastward and photos c) and d) were taken looking westward.

3. Methodology

3.1 Digital grain-size analysis (DGS)

To address the practical limitations of using physical sampling methods to determine sediment size distribution at gravel beaches, the present study adopts a DGS collection method. The method required digital samples (surface photographs) to be taken and then processed through a software package developed by Buscombe *et al.*, (2013). The interested reader is directed to this paper for further details.

The collection method consisted of taking multiple surface photographs at each of the study sites. Photographs were taken using a Sony ILCE-6000 24.3 megapixel digital camera, mounted on a metal arm fixed to a survey pole (Figure 12).

For best results the DGS software requires approximately 1000 grains to be present within a digital sample. Due to the large variability that exists in sediment grain-size both at and between gravel systems, it was decided to have the option to operate the camera at 3 different fixed heights (H1, 2.5 m; H2, 1.3 m; H3, 0.5 m). This ensured a sufficient number of grains would be present in the sample even when the material of the site was very coarse.

For sample collection, the camera was set to have a 10 second timer on its Intelligent Auto setting, allowing it to automatically identify the characteristics of the scene and focus correctly before shooting the photo. Photos were taken ensuring a transverse (parallel) plane with the beach surface (Figure 12)

At each of the sites, samples were taken, staking out a predefined cross-shore profiles using a hand held GPS. The times of each photo were recorded for each of the survey points, allowing each photo to be georeferenced to aerial imagery.

At each study site, digital samples were collected from up to 10 cross-shore profiles with a maximum of 7 sample points per profile. Each of the profiles had a minimum alongshore spacing of 50 m, and each survey point had a minimum cross-shore spacing of 10 m. Due to future nourishment efforts only requiring the sediment distribution of the upper gravel section of the sites, when the material changed from gravel to sand, no digital sample was taken. The table below summaries the total number of profiles and samples taken at each of the study sites (Table *1*).

For very coarse grain-sizes (cobbles; D = >64 mm) H1 was required to maximise the number of cobbles in the image. Multiple digital samples were taken at the same survey point to compare the outputs produced by the DGS for consistency. This was undertaken to confirm that results were accurate when less than 1000 samples were present in the sample.

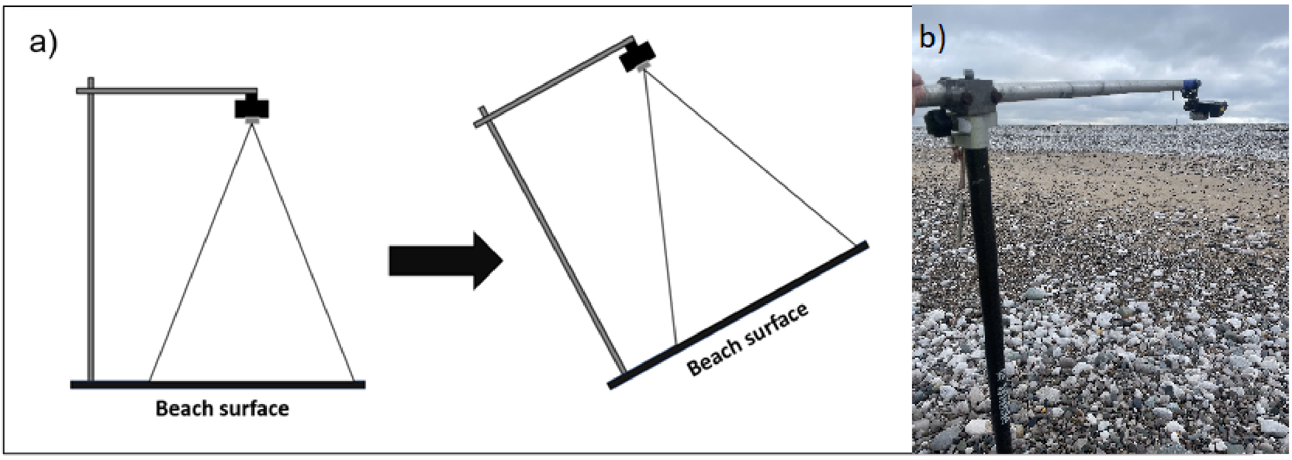

Figure 12: Diagram of digital sampling collection method a) and photograph the actual camera and mounting system used for data collection at each of the five study sites b).

Table 1: Summary table of the number of survey profiles, total number of digital samples, and proportion of H1 (2.5 m), H2 (1.3 m), and H3 (0.5 m) taken at each of the five study sites.

Site	**Profiles**	**Total samples**	**H1**	**H2**	**H3**
Pensarn	10	52	12	34	6
Morfa Dinlle	10	50	6	35	9
Borth	10	36	9	26	1
Amroth	9	30	16	14	0
Leys	9	46	31	15	0

To process digital samples, the DGS software requires the resolution (mm/pixel) of the image to be defined. To set the resolution, a grid of known size was photographed on a level surface at each of the 3 height intervals and the resolution was then calculated by dividing the actual width of the grid in mm by its pixel width in the image (Figure *13*). The digital samples were then batch processed, for each of the height intervals, using the DGS graphic user interface (GUI) developed by Buscombe *et al.,* (2013). The “ROI whole” was selected for all images (Figure *14*).

Figure 13: Example of H1 resolution grid calculation. Photo taken ensuring transverse (parallel) plane with concrete floor. Resolution was calculated using 2 sets of images to ensure a high level of confidence. The same method was applied for calculating the H2 and H3 resolutions.

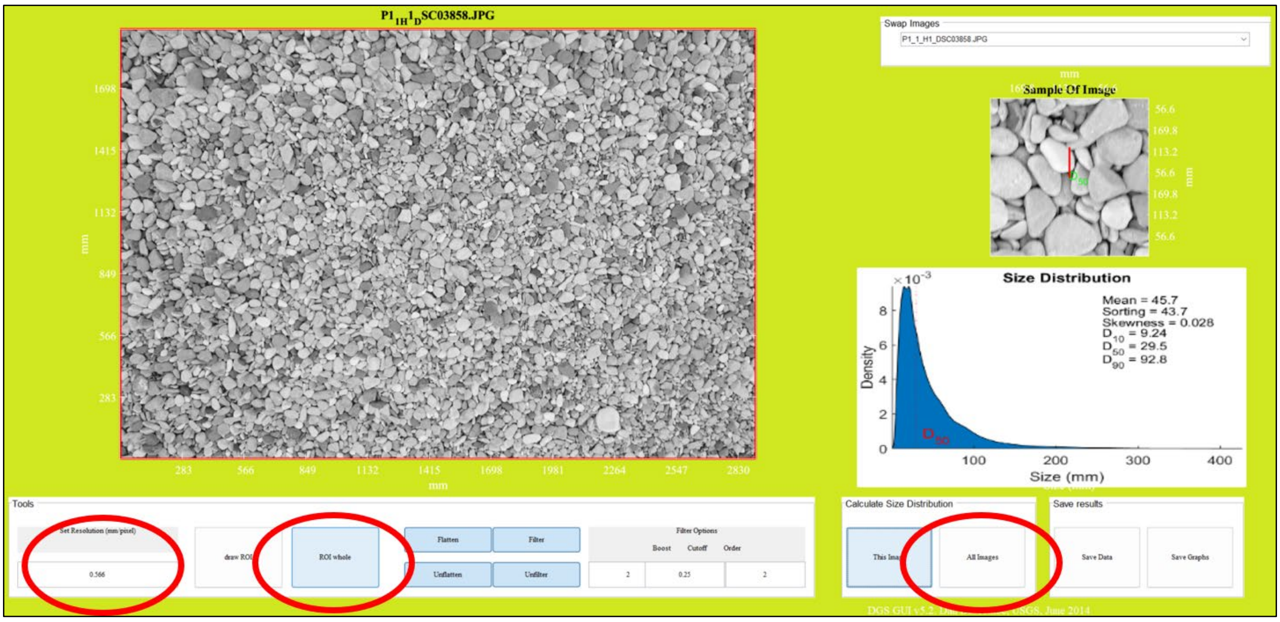

Figure 14: DGS GUI, with digital sample P1_1_H1 (profile 1, point 1, height 1) from Pensarn loaded and processed (Resolution 0.566). Software allows batch processing of all images with the same resolution. Region of interest (ROI) can be drawn, or set to use whole image.

3.2 Minerology

In order to provide an assessment of the minerology of the beach material, physical sediment samples were collected at each of the study sites (Figure 15). This was done by taking a small grab sample of sediment from each of the survey points where digital samples were collected.

Employing a geological expert, each of the physical samples were examined to determine the rock type of the individual grains (gravel/cobble)and to compare if these were consistent with what would be expected for the study site according to geological maps of the local area (BGS GeoIndex: https://mapapps2.bgs.ac.uk/geoindex/home.html).

The sample sets were then sub-sampled by randomly selecting 10 individual grains for each of the study sites. These grains were tested according to the Mohs scale of mineral hardness, using a steel rod to characterize the scratch resistance of the material.

Figure 15: Selection of physical samples collected at Pensarn a), Morfa Dinlle b), Borth c), Amroth d), and Leys e). Photos help to illustrate the colour and size differences in material between the five study sites.

4. Results

4.1 Sediment grain-size distribution

The results of the DGS analysis for the five study sites are shown below (Figures 16 to 25) (See Appendix A for full summary tables of results).

The Pensarn study site was found to be 76% gravel and 24% cobbles, and had an overall arithmetic mean grain-size of 47 mm. The mean D_{10}, D_{50}, and D_{90} values were 11 mm, 35 mm, and 95 mm, respectively; where D_{10} is the value that 10% of the sample is smaller than, D_{50} the value that 50% of the sample is smaller than (the median value), and D_{90} the value that 90% of the sample is smaller than. The site on average shows an approximately symmetrical distribution. However, some bimodality does occur for some of the samples (Figure *16*). The grain size distribution map for Pensarn shows most of the gravel berm to be formed from gravels with D_{50} values of 20-40 mm (Figure *17*). The more exposed sections to the western end of the survey area contained coarser material. It is not possible to say if similar size material was present in the eastern area too but simply buried.

The Morfa Dinlle study site was found to be around 77% gravel and 23% cobbles, and had an overall arithmetic mean grain size of 45 mm. The mean D_{10}, D_{50}, and D_{90} values were 12 mm, 35 mm, and 88 mm, respectively. The site generally shows an approximately symmetrical distribution, with some variability and bimodality occurring for some samples (Figure *18*). The grain size distribution map for Morfa Dinlle shows the majority of the upper and middle portions of the gravel berm to be formed from gravels with D_{50} values of 20-40 mm, and the lower portions to be formed of gravels with D_{50} values of 5-20 mm. The lower part of the profile at the southern end of the study site is shown to have very coarse material present. However, it should be noted that this was not present along the majority of the site (Figure *19*).

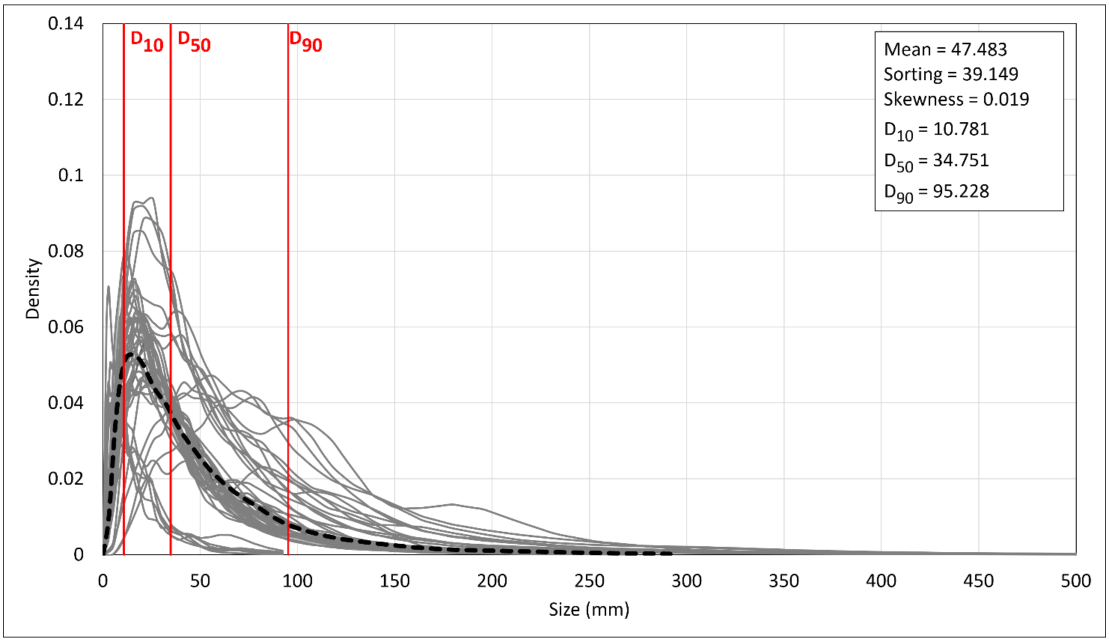

Figure 16: Pensarn sediment grain-size envelope plot produced from the DGS output, with probability density on the vertical axis and grain size on the horizontal axis. The plot includes all individual digital samples (grey lines) and the average of all digital samples (black dashed line). Mean D_{10}, D_{50}, and D_{90} values are also indicated (red vertical lines).

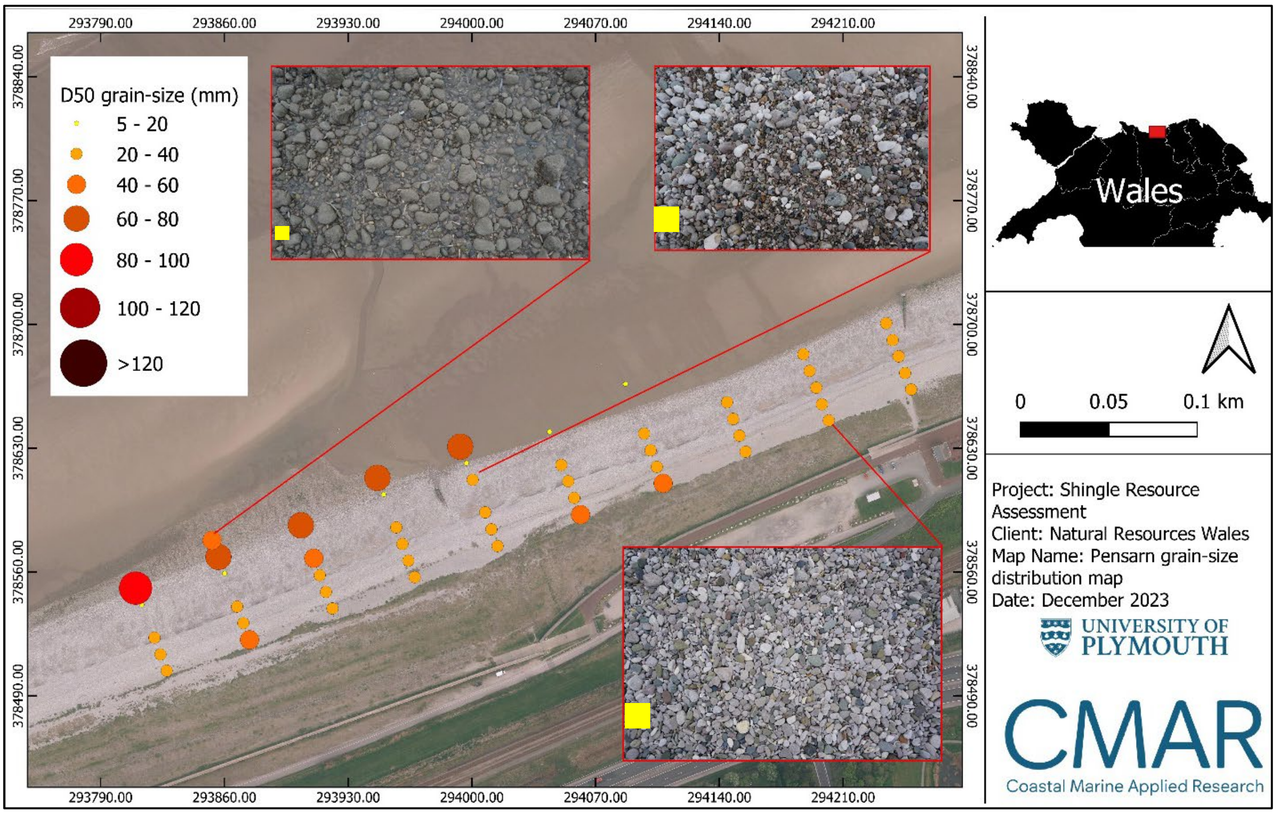

Figure 17: Pensarn grain-size distribution map. The plot shows the D_{50} (mm) of each of the digital samples collected at the site. Images of 3 digital samples from survey profiles 2, 6, and 9 have been included. Yellow scale squares represent 15 x 15 cm Aerial images courtesy of the WCMC (https://www.wcmc.wales/).

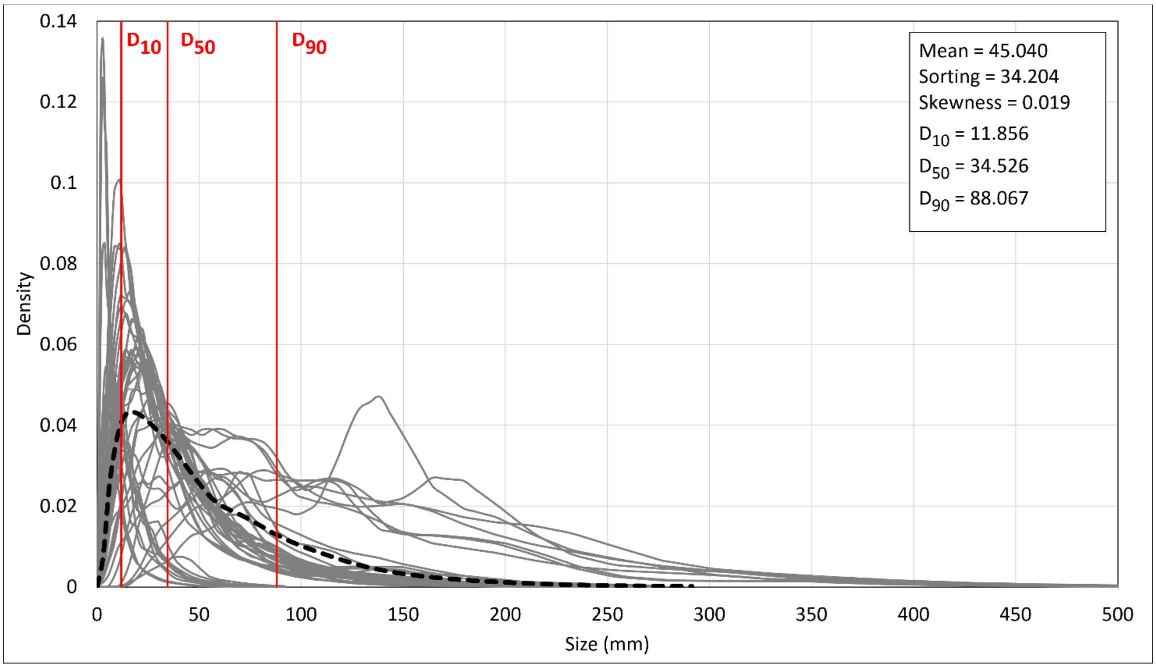

Figure 18: Morfa Dinlle sediment grain-size envelope plot produced from the DGS output, with probability density on the vertical axis and grain size on the horizontal axis. The plot includes all individual digital samples (grey lines) and the average of all digital samples (black dashed line). Mean D10, D50, and D90 values are also indicated (red vertical lines).

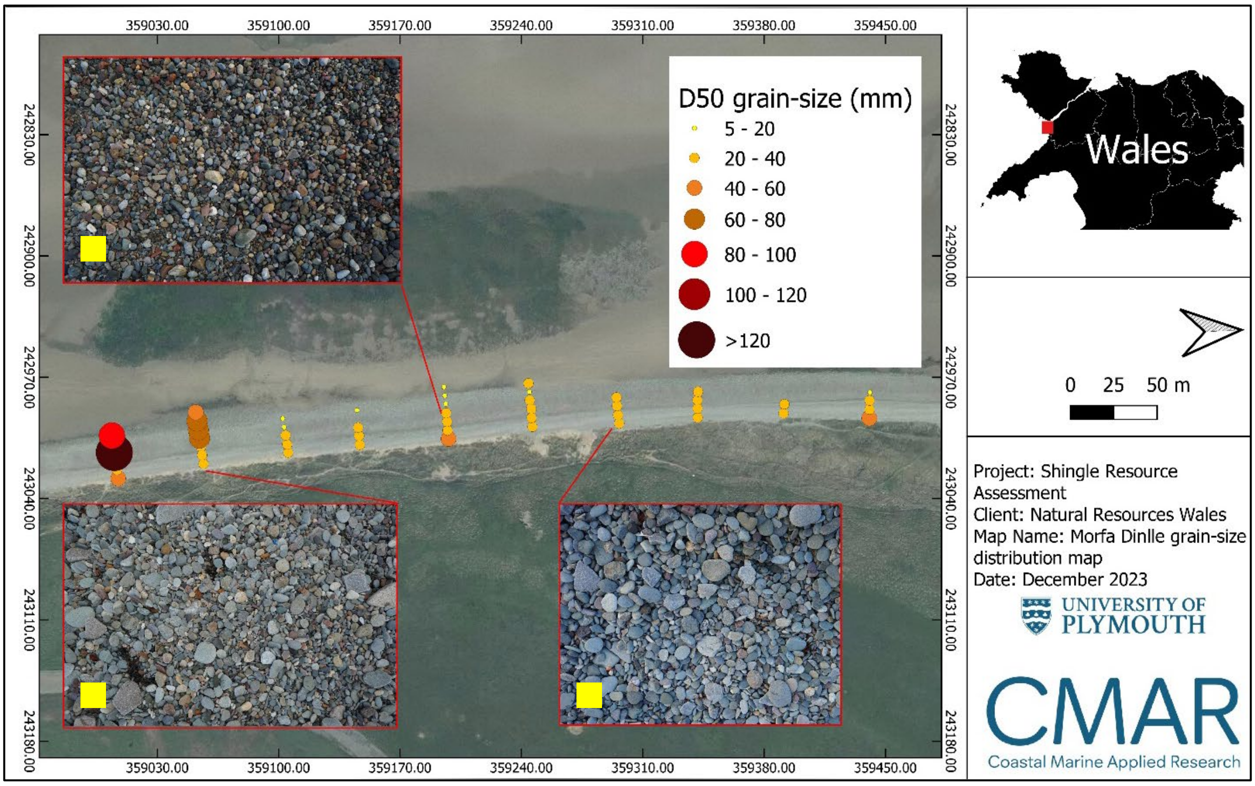

Figure 19: Morfa Dinlle grain-size distribution map. The plot shows the D_{50} (mm) of each of the digital samples collected at the site. Images of 3 digital samples from survey profiles 2, 5, and 7 have been included. Yellow scale squares represent 15 x 15 cm. Aerial images © Bluesky International Limited and Getmapping 2024.

The Borth study site was found to be around 68% gravel and 31% cobbles, and had an overall arithmetic mean grain size of 57 mm. The mean D_{10}, D_{50}, and D_{90} values were 15 mm, 43 mm, and 112 mm, respectively (Figure *20*). The grain-size distribution map for Borth shows much of the upper and middle portions of the profile to be formed of coarse gravels with D_{50} values of 40-60 mm (Figure *21*).

The Amroth study site was found to be around 52% gravel and 48% cobbles, and had an overall arithmetic mean grain size of 83 mm. The mean D_{10}, D_{50}, and D_{90} values were 26 mm, 68 mm, and 153 mm, respectively (Figure *22*). Significant variability in sediment grain size distribution between the western, middle, and eastern sections of the site is observed in both alongshore and cross-shore directions, with the middle sections of the site generally showing smaller grain sizes (Figure *23*).

The Leys study site was found to be around 37% gravel and 63% cobbles, and had an overall arithmetic mean grain size of 99 mm. The mean D_{10}, D_{50}, and D_{90} values were 33 mm, 84 mm, and 177 mm, respectively (Figure *24*). The grain-size distribution map for Leys shows there to be significant variability in grain sizes in both alongshore and cross-shore direction (Figure *25*).

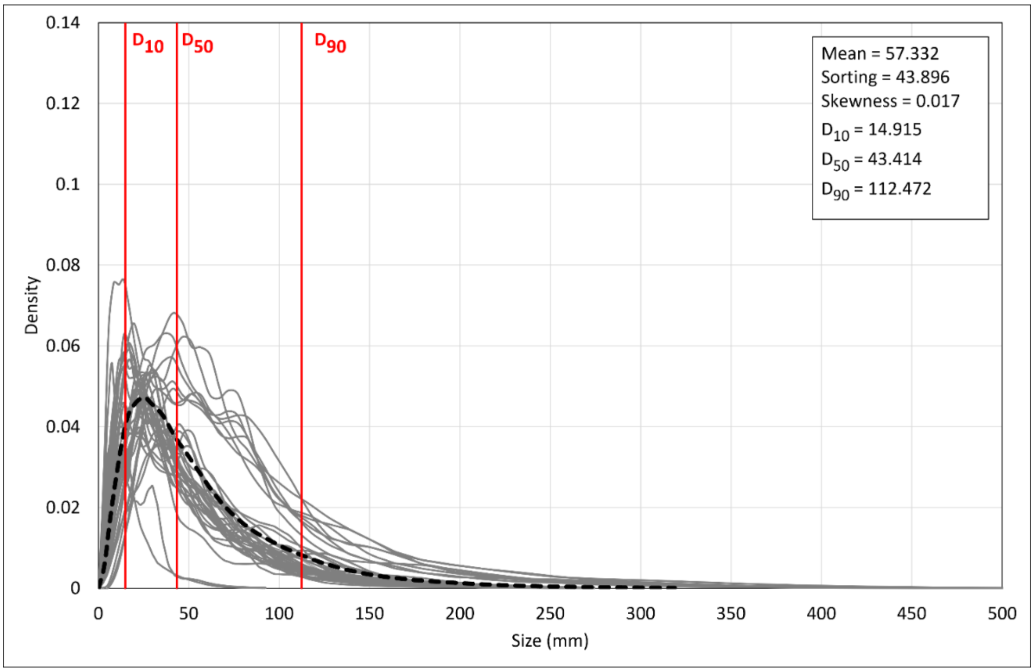

Figure 20: Borth sediment grain-size envelope plot produced from the DGS output, with probability density on the vertical axis and grain size on the horizontal axis. The plot includes all individual digital samples (grey lines) and the average of all digital samples (black dashed line). Mean D10, D50, and D90 values are also indicated (red vertical lines).

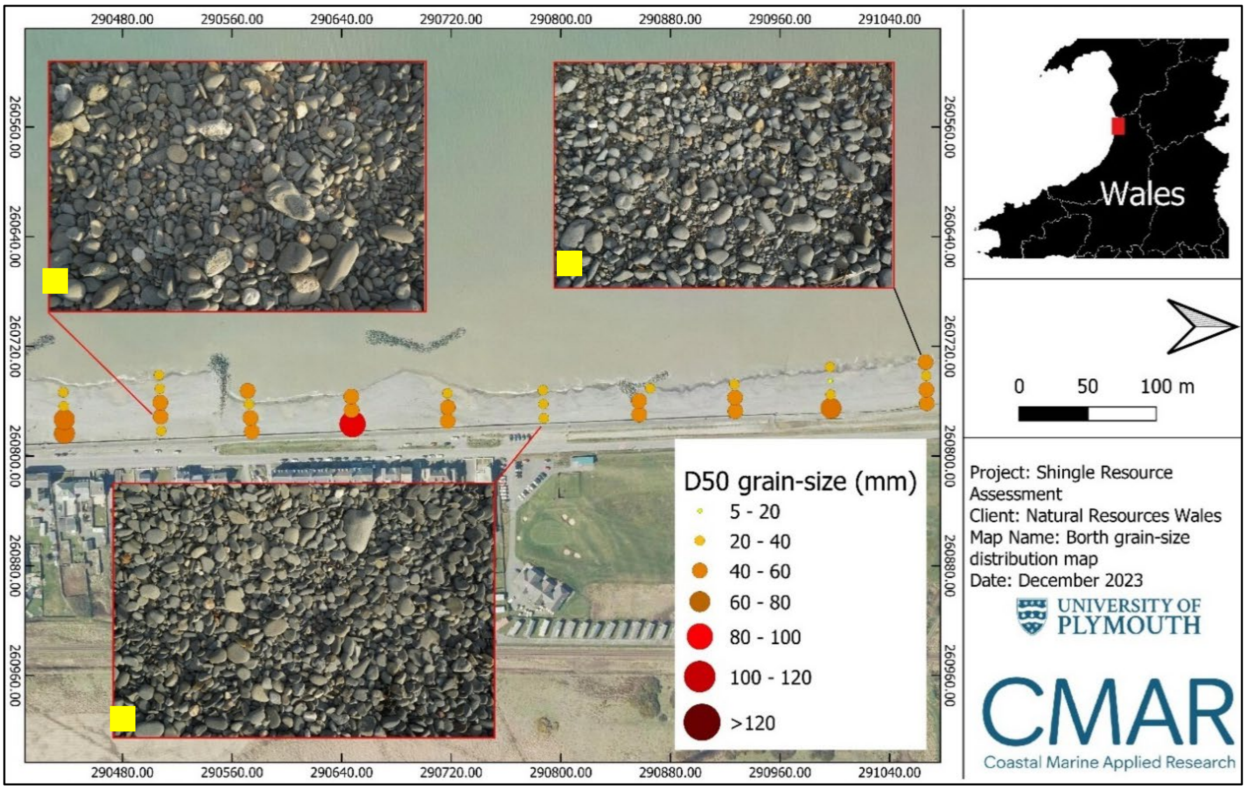

Figure 21: Borth grain-size distribution map. The plot shows the D_{50} (mm) of each of the digital samples collected at the site. Images of 3 digital samples from survey profiles 1, 5, and 9 have been included. Yellow scale squares represent 15 x 15 cm. Aerial images © Bluesky International Limited and Getmapping 2024.

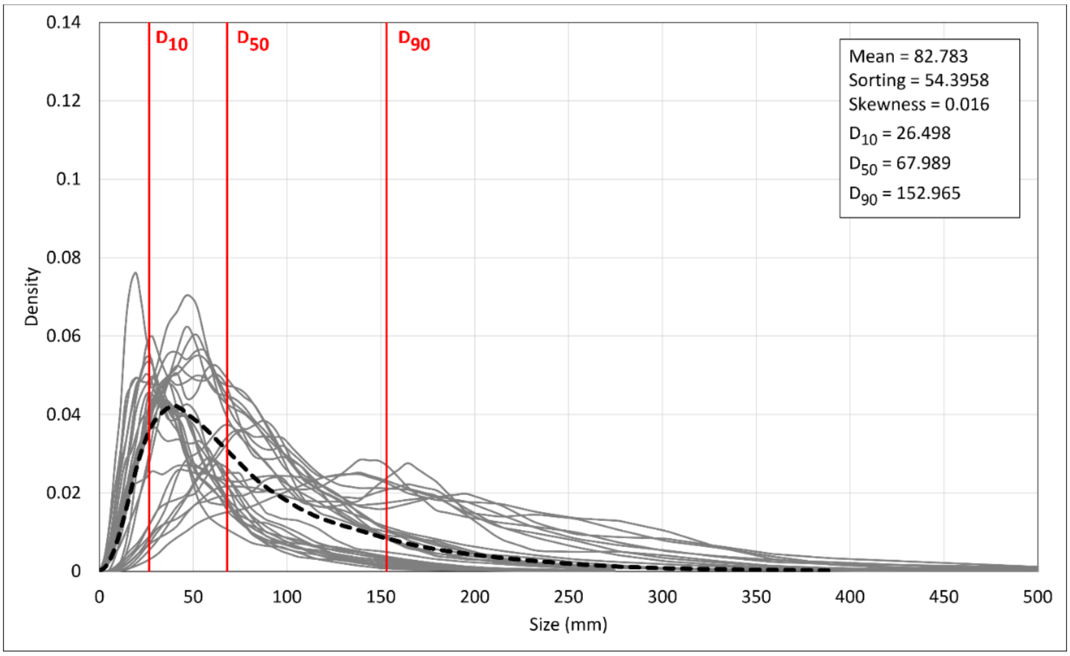

Figure 22: Amroth sediment grain-size envelope plot produced from the DGS output, with probability density on the vertical axis and grain size on the horizontal axis. The plot includes all individual digital samples (grey lines) and the average of all digital samples (black dashed line). Mean D10, D50, and D90 values are also indicated (red vertical lines).

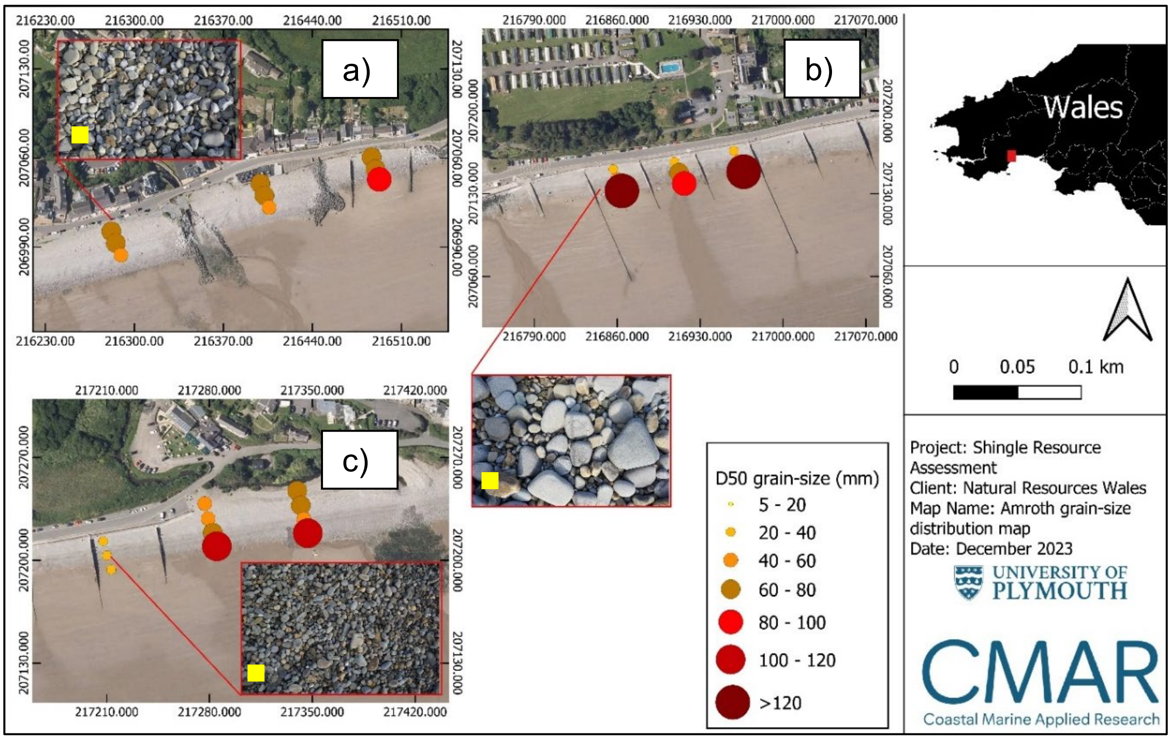

Figure 23: Amroth grain-size distribution map. The plot shows the D_{50} (mm) of each of the digital samples collected at the site. The site has been divided into 3 sections: western profiles 1, 2 and 3 (a); middle profiles 4, 5 and 6 (b); eastern profiles 7, 8, and 9 (c). Images of 3 digital samples from survey profiles 1, 4, and 7 have been included. Yellow scale squares represent 15 x 15 cm. Aerial images © Bluesky International Limited and Getmapping 2024.

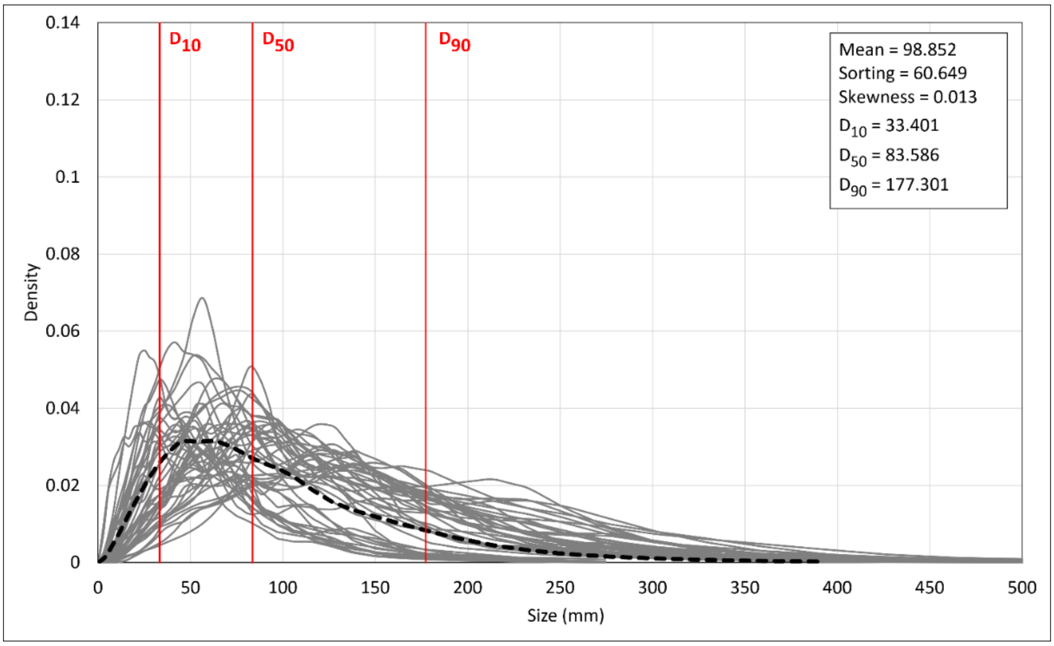

Figure 24: Leys sediment grain-size envelope plot produced from the DGS output, with probability density on the vertical axis and grain size on the horizontal axis. The plot includes all individual digital samples (grey lines) and the average of all digital samples (black dashed line). D10, D50, and D90 values are also indicated (red vertical lines).

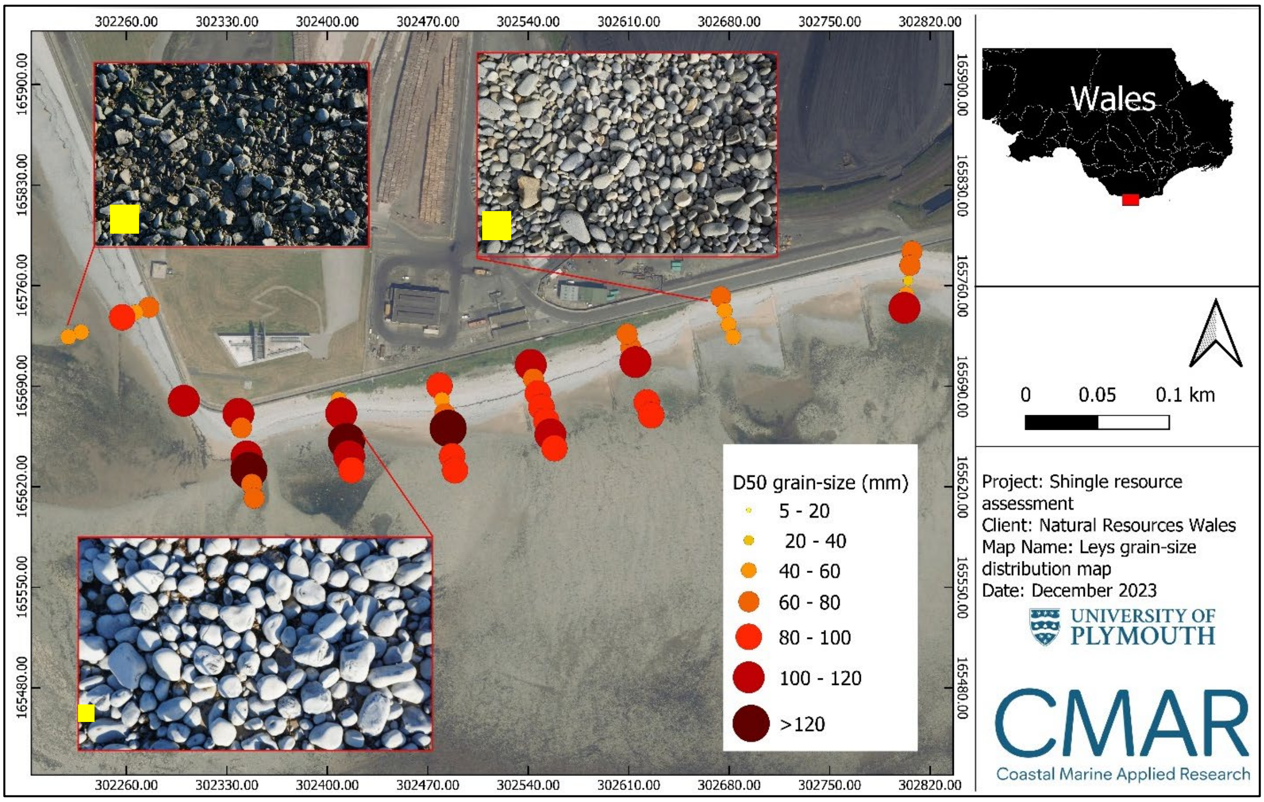

Figure 25: Leys grain-size distribution map. The plot shows the D_{50} (mm) of each of the digital samples collected at the site. Images of 3 digital samples have been included. Yellow scale squares represent 15 x 15 cm. Aerial images © Bluesky International Limited and Getmapping 2024.

4.2 Minerology assessment

This section presents the results of the Mohs scale of mineral hardness test for each of the study sites (Tables 2 to 6) and provides a brief overview of the types of rock found at the sites in relation to the geology of the area according to geological maps.

The Pensarn study site is located within the Warwickshire group which consists of sandstones, siltstones and mudstones, with the occasional occurrence of coal measures. To the west of the site there is a portion of shallow marine limestones, and further west are more sandstones, mudstones and siltstones.

The samples collected at Pensarn were found to consist of a mixture of sandstones, mudstones and limestones, which is as expected for the area. Results of the Mohs scale found the hardness of the material to sit between 5 and 6 (arbitrary), with an average hardness of 5.6 (Table *2*).

The Morfa Dinlle study site straddles the boundary of the Nant Ffrancon subgroup (mudstones and sandstones), and the Fachwen formation (sandstones and siltstones with occasional extrusive volcanic material). The area also has significant amount of volcanic material present from the Padarn Tuff formation, located further south, just north of the Llyn peninsula.

The samples collected at Morfa Dinlle were found to be consistent with what would be expected for the area, with the samples consisting of sandstones, mudstones, siltstones and volcanic extrusives including rhyolites and tuffs. Results of the Mohs scale found the hardness of the material to sit between 6 and 7 (arbitrary), with an average hardness of 6.5 (Table *3*).

Table 2: Results of Mohs scale of mineral hardness test for Pensarn samples. The rock type has also been classified for each of the 10 subsetted samples.

Sample	Type	Mohs scale
1	Mudstone	5
2	Mudstone	5
3	Quartzite sandstone	6
4	Limestone	5
5	Mudstone	6
6	Limestone	6
7	Sandstone	6
8	Limestone	6
9	Sandstone	6
10	Sandstone	5
Average	N/A	5.6

Table 3: Results of Mohs scale of mineral hardness test for Morfa Dinlle samples. The rock type has also been classified for each of the 10 subsetted samples.

Sample	**Type**	**Mohs scale**
1	Tuff	7
2	Sandstone	6
3	Sandstone	6
4	Siltstone	6
5	Volcanic extrusive	7
6	Rhyolite	7
7	Tuff	7
8	Rhyolite	7
9	Sandstone	6
10	Mudstone	6
Average	N/A	6.5

Table 4: Results of Mohs scale of mineral hardness test for Borth samples. The rock type has also been classified for each of the 10 subsetted samples.

Sample	**Type**	**Mohs scale**
1	Sandstone	6
2	Mudstone	5
3	Mudstone	5
4	Greywacke Sandstone	7
5	Mudstone	5
6	Sandstone	6
7	Greywacke Sandstone	6
8	Mudstone	6
9	Greywacke Sandstone	7
10	Mudstone	6
Average	N/A	5.9

The Borth study site is located on the Borth mudstone formation, which consists of turbidite mudstones and sandstones. This is consistent with what was found in the samples from the site, with turbidite mudstones and sandstones both present in the sediment sample. Additionally, silica rich greywackes were found within the sample. These are likely to have originated from the Aberystwyth grits, located south of the site, and should be harder than the local material of the site. Results of the Mohs scale found the hardness of the material to sit between 5 and 7 (arbitrary), with an average hardness of 5.9. The hardest material present was found to be greywacke sandstone (Table *4*).

The Amroth study site is located on the south Wales coal seams, which generally consists of sandstones and mudstones. The geology of the area is complex, and it is likely the beach is formed of a large mixture of material from the surrounding area. The samples collected at the site were found to consist of sandstones, mudstones, and limestones. Results of the Mohs scale found the hardness of the material to sit between 6 and 7 (arbitrary), with an average hardness of 6.7 (Table *5*).

The Leys study site is located on the Lias group, which has a very uniform geology, consisting of mudstones and limestones. Samples were consistent with this, with only mudstone and limestone being present. Results of the Mohs scale found the hardness of the material to sit between 5 and 6 (arbitrary), with the mudstones showing a consistent hardness of 6, and the limestones generally found to be softer (Table *6*).

Table 5: Results of Mohs scale of mineral hardness test for Amroth samples. The rock type has also been classified for each of the 10 subsetted samples.

Sample	**Type**	**Mohs scale**
1	Sandstone	7
2	Sandstone	6
3	Mudstone	7
4	Sandstone	7
5	Sandstone	7
6	Sandstone	7
7	Sandstone	7
8	Limestone	6
9	Mudstone	7
10	Sandstone	6
Average	N/A	6.7

Table 6: Results of Mohs scale of mineral hardness test for Leys samples. The rock type has also been classified for each of the 10 subsetted samples.

Sample	**Type**	**Mohs scale**
1	Mudstone	6
2	Mudstone	6
3	Mudstone	6
4	Mudstone	6
5	Mudstone	6
6	Mudstone	6
7	Limestone	5
8	Limestone	5
9	Limestone	6
10	Limestone	5
Average	N/A	5.7

4.3 BGS: Directory of mines and quarries

It is beyond the scope of this project to provide a comprehensive analysis of viable nourishment sources for the five sites studied. Previous work has identified that land based sources of material are twice as expensive as marine aggregate supplies (Winnard *et al.,* 2011). However, using the BGS Directory of Mines and Quarries 2020 (Cameron, et al., 2020), possible land-based reserves of material in Wales have been identified for each of the five study sites. The BGS directory listed 14 sand and gravel quarries in Wales, five of which were found to be closed/inactive at present (See appendix B for full summary of quarries).

To determine the material available at the quarries listed by the BGS, each quarry operator had to be contacted directly and asked to provide the sizes of material they had available.

From the information provided by the quarries, and working on the basis that a 50 km radius would be the maximum transport distance from quarry to beach (the previous cut-off distance used by NRW), it was determined that for Pensarn, Morfa Dinlle, and Borth, the most appropriate land-based source of material would be the Cefn Graianog Quarry (operated by the Tudor Griffiths Group). The site has reserves of well rounded quartzite glaciofluvial deposits available in size ranges of 4-300 mm, and is now the only sand and gravel quarry operating in Gwynedd. The quarry has previously provided rounded boulders, gravel and sand for numerous beach nourishment projects along the north and west coastline of Wales.

The availability of suitable land-based sources of material for the sites in the south of Wales is limited. The majority of the quarries operating nearby are predominantly sand quarries, with limited gravel resource. However, the Cware Pantgwyn Quarry has a reserve of around 3000 tonnes of rounded glaciofluvial gravel with diameters ranging from 70–130 mm. This material is mostly considered as a by-product of the sand quarrying, with little demand for the larger sizes of material, and may provide a suitable option for nourishment at the Amroth site. This nourishment could be further supplemented with material sourced from the Cware Trefigin and Penparc quarries (Appendix B).

The Leys site, the most coarse of the five study sites, has no land-based gravel quarries within the ideal transport distance that would be able to provide large enough material for nourishment at the site. There is a limestone rock quarry nearby that may provide a viable alternative. The advantages of using locally sourced quarried rock from a FCERM perspective include it being relatively cheap to source and would have a reduced cost in terms of carbon expenditure. Additionally, the movement of the material would be reduced due to the angular clasts interlocking. The disadvantages would primarily be from amenity and nature conservation viewpoints. However, angular limestone is already present at the Leys site (Figure 15e & Table 6) , and it has been shown that in moderate to high energy environments rounding of relatively soft rocks (such as limestone) can occur within 10-20 years, giving it a more natural appearance (Pye & Blott, Advice on Sustainable Management of Coastal Shingle Resources. NRW Report No: 273, 167pp, 2018). Further work would be required to determine if this would be an appropriate option for the Leys site.

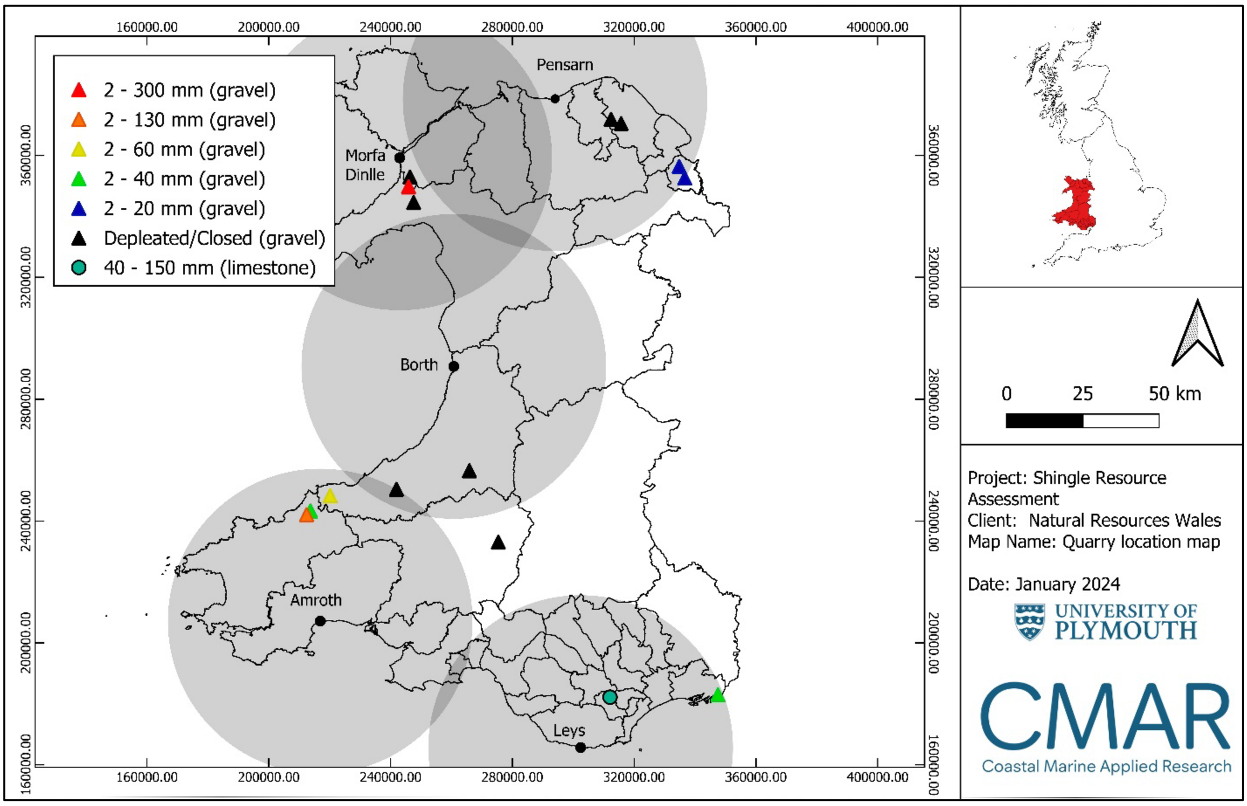

Figure 26: Location map of all gravel quarries in Wales according to the BGS Directory of Mines and Quarries 2020. Light grey circles represents the ideal 50 km radius transport distance (previous cut-off used by NRW) from each of the five study sites. Location of a limestone quarry that could provide material for Leys has also been included

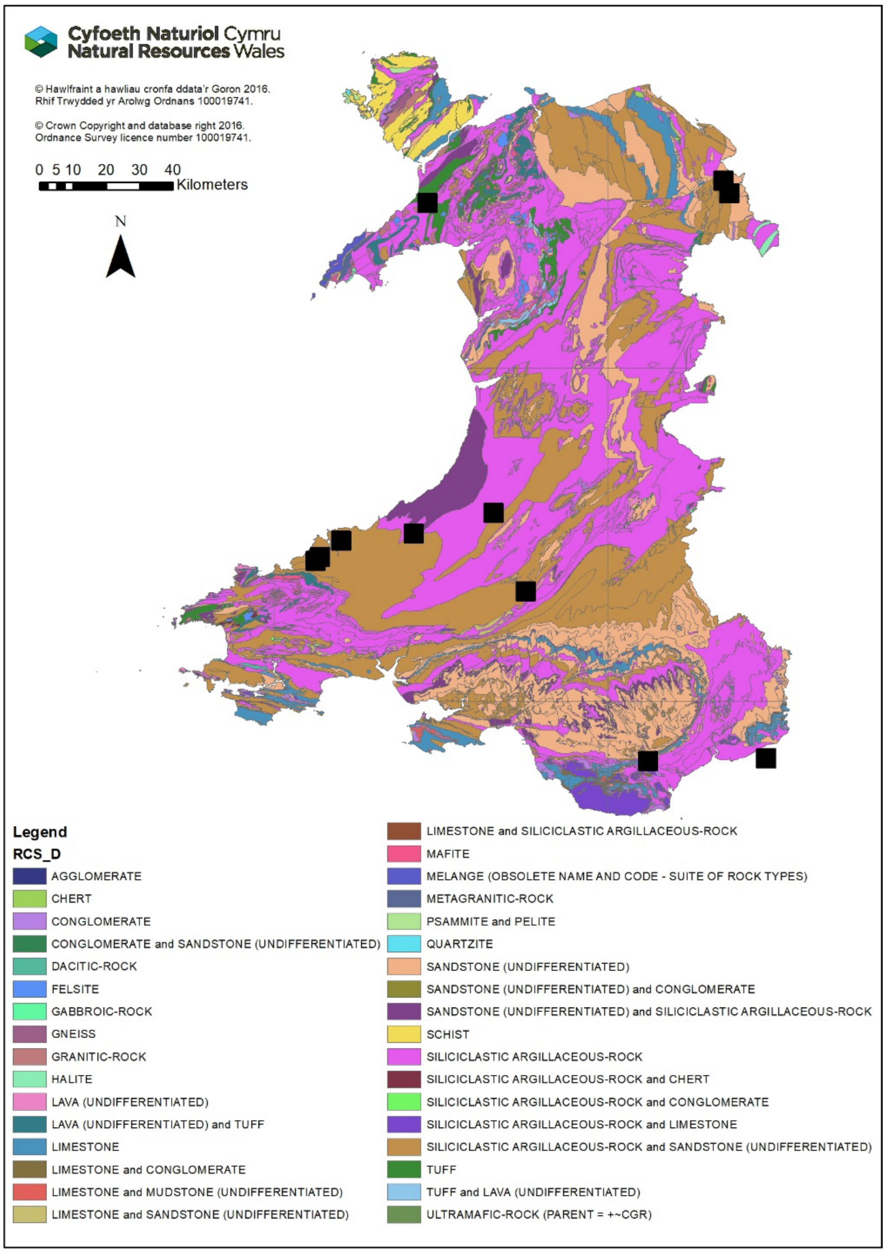

Figure 27: A map of Wales showing bedrock, mapped using the British Geological Survey (BGS) Rock Classification Scheme. The image is based on the BGS 1:625,000 maps. Black squares indicate the location of active quarries that may be able to supply appropriate material. Contains British Geological Survey materials © UKRI 2024.

5. Summary

In summary, adopting a DGS analysis method, this study has provided a characterisation of the sediment grain-size distribution and minerology of five key gravel sites that give a representative geographic spread around the coastline of Wales. The results of this work will provide coastal managers with the necessary data to help them make informed decisions on the appropriate management approaches for both the five tested sites and other shingle beaches around Wales. Additionally, this work has highlighted how semi-autonomous image processing techniques are able to overcome the practical limitations of physical sampling methods on gravel beaches, providing a methodology that could be adopted by coastal management authorities on a wider scale.

The Cefn Graianog Quarry is the most suitable land-based source of material for gravel sites located on the north and west coastline of Wales. Sourcing material for coarse gravel sites located along the south coastline of Wales will be a more significant challenge for future nourishment efforts. The active quarries located in the south of Wales are predominantly sand based, with fairly limited gravel resource available. However, these quarries sometimes have reserves of larger material that is mostly considered as a by-product of quarrying, and has less commercial demand. These limited reserves of material could potentially be used for nourishment. Alternatively, locally sourced quarried rock may provide a viable option where sourcing gravel cannot be economically justified. Further work would be required to determine if this would be an appropriate option for coarse gravel sites in South Wales.

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6. Appendices

Appendix A: Summary tables of DGS analysis results

Table A1: Summary table of results of DGS analysis for Pensarn. Sample ID, corresponding Easting and Northing coordinates, arithmetic mean, arithmetic sorting, arithmetic skewness, arithmetic kurtosis, and D5 to D95 values.

Sample ID	Easting	Northing	Mean	Sort	Skew	Kurt	D_{5}	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_{95}
Pensarn_P1_1_H1	294248	378663	45.7	43.7	0.028	0.147	6.3	9.2	12.0	16.2	29.5	55.6	73.5	92.8	124.6
Pensarn_P1_2_H1	294245	378673	49.7	46.7	0.026	0.130	7.1	10.4	13.7	18.1	32.0	60.6	81.3	102.9	136.9
Pensarn_P1_3_H1	294241	378682	55.0	52.0	0.028	0.143	7.8	11.3	14.7	19.8	36.0	66.1	85.6	112.9	154.3
Pensarn_P1_4_H1	294238	378691	53.3	51.3	0.026	0.128	7.1	10.6	13.9	18.9	34.4	65.3	84.4	107.6	152.5
Pensarn_P1_5_H2	294234	378701	47.5	38.8	0.017	0.065	6.7	10.2	13.9	19.1	34.3	60.6	79.7	100.4	127.4
Pensarn_P2_8_H2	294202	378646	38.6	33.5	0.020	0.087	5.9	8.2	10.7	14.3	26.9	49.5	64.2	78.7	105.6
Pensarn_P2_9_H2	294198	378655	38.3	34.1	0.024	0.109	6.0	8.4	10.9	14.4	26.4	48.0	60.6	76.7	104.6
Pensarn_P2_10_H2	294195	378664	47.3	38.5	0.019	0.075	7.7	10.9	14.1	18.9	35.0	60.2	78.3	96.6	121.6
Pensarn_P2_11_H2	294191	378674	43.4	35.0	0.019	0.080	7.0	9.8	12.8	17.3	32.0	56.7	70.7	85.9	110.8
Pensarn_P2_12_H2	294188	378683	37.5	31.6	0.022	0.096	6.0	8.8	11.7	15.7	27.3	44.9	58.4	74.8	101.7
Pensarn_P3_15_H2	294155	378628	38.0	34.6	0.021	0.092	4.9	7.1	9.5	13.0	24.9	48.7	65.2	80.3	105.3
Pensarn_P3_16_H2	294151	378637	46.0	36.4	0.019	0.082	7.8	11.0	14.2	19.1	33.9	59.7	74.7	89.5	116.1
Pensarn_P3_17_H2	294148	378647	46.4	35.9	0.018	0.077	8.0	11.7	15.3	20.1	35.1	59.4	76.4	90.5	114.5
Pensarn_P3_18_H2	294144	378656	47.8	36.7	0.018	0.075	8.1	11.8	15.3	20.3	36.1	61.8	78.2	93.8	116.5
Pensarn_P4_22_H1	294108	378610	61.3	53.9	0.022	0.098	9.1	13.5	17.6	24.0	42.0	76.8	100.7	126.1	167.3
Pensarn_P4_23_H2	294105	378620	36.5	32.1	0.024	0.113	5.6	7.8	10.6	14.5	25.6	44.9	58.6	72.2	96.9
Pensarn_P4_24_H2	294101	378629	51.5	40.6	0.015	0.061	6.6	10.1	14.0	19.9	37.4	71.4	89.0	105.3	125.4
Pensarn_P4_25_H2	294097	378638	44.1	36.8	0.021	0.089	6.5	9.7	13.2	18.0	32.8	55.2	69.3	87.7	116.4
Pensarn_P4_28_H3	294087	378666	19.8	15.8	0.015	0.053	3.4	4.7	6.1	8.0	14.2	25.5	32.9	42.5	53.0
Pensarn_P5_29_H1	294061	378593	66.7	58.2	0.021	0.091	9.0	13.1	17.6	24.8	47.0	83.4	108.3	141.2	181.4
Pensarn_P5_30_H2	294058	378602	42.0	34.8	0.020	0.085	6.8	9.7	12.8	16.9	30.7	52.6	66.8	84.4	112.3
Pensarn_P5_31_H2	294055	378611	36.3	32.6	0.023	0.103	5.1	7.4	9.8	13.3	25.1	45.2	58.9	74.9	99.5
Pensarn_P5_32_H2	294051	378621	41.2	35.1	0.023	0.104	6.4	9.5	12.9	17.6	30.0	48.9	63.0	81.8	110.1
Pensarn_P5_34_H3	294044	378639	19.0	17.0	0.017	0.060	2.4	3.4	4.5	6.3	12.9	24.7	31.3	42.6	55.3
Pensarn_P6_36_H2	294015	378575	34.2	31.2	0.024	0.110	4.8	7.0	9.3	12.4	23.3	41.5	55.3	71.2	94.5
Pensarn_P6_37_H2	294011	378584	40.9	34.7	0.020	0.087	6.4	9.0	11.9	15.9	28.9	53.1	67.7	82.4	107.6
Pensarn_P6_38_H2	294008	378594	47.9	37.4	0.019	0.079	7.8	11.3	15.1	20.6	36.2	62.9	78.7	93.2	116.7
Pensarn_P6_40_H2	294000	378612	49.5	39.9	0.017	0.063	8.0	11.4	15.1	20.1	36.6	62.8	81.5	102.7	131.7
Pensarn_P6_41_H3	293997	378622	24.8	22.1	0.012	0.034	2.3	3.6	5.0	7.6	16.1	34.2	50.3	61.9	71.7
Pensarn_P6_42_H1	293993	378631	83.9	62.7	0.021	0.097	15.7	21.1	28.0	38.9	67.7	103.6	125.2	152.1	202.3
Pensarn_P7_43_H2	293968	378557	39.8	36.3	0.022	0.096	5.7	8.0	10.6	14.6	27.3	49.3	64.9	82.4	111.5
Pensarn_P7_44_H2	293964	378566	48.8	37.2	0.017	0.071	8.1	11.5	15.3	21.0	38.2	62.2	77.1	95.5	124.2
Pensarn_P7_45_H2	293961	378576	42.2	36.4	0.022	0.093	6.5	9.4	12.5	16.6	29.5	52.7	69.9	86.1	110.0
Pensarn_P7_46_H2	293957	378585	47.5	38.8	0.019	0.071	7.7	11.2	14.7	19.6	35.1	58.2	75.4	98.5	129.8
Pensarn_P7_48_H3	293950	378604	15.1	15.3	0.020	0.073	1.3	2.0	2.8	4.1	9.6	18.7	26.5	34.6	48.0
Pensarn_P7_49_H1	293947	378613	93.5	69.0	0.020	0.078	20.7	28.2	35.1	45.3	73.9	111.8	138.9	173.7	240.2
Pensarn_P8_50_H2	293921	378539	40.1	36.4	0.023	0.097	5.9	8.5	11.3	15.4	27.5	48.4	63.7	84.0	113.4
Pensarn_P8_51_H2	293917	378549	47.5	37.6	0.018	0.072	7.4	10.7	14.0	19.4	35.9	60.1	79.4	96.6	120.2
Pensarn_P8_52_H2	293914	378558	42.4	36.2	0.021	0.086	6.7	9.6	12.4	16.6	29.6	53.7	67.9	86.6	115.7
Pensarn_P8_53_H2	293911	378568	53.9	41.5	0.014	0.056	8.4	11.6	15.3	20.5	40.5	75.3	91.0	106.1	130.4
Pensarn_P8_55_H1	293903	378586	89.1	65.5	0.017	0.072	16.6	24.0	31.4	41.0	69.9	112.9	141.2	173.0	218.1
Pensarn_P9_57_H1	293874	378522	61.1	56.6	0.024	0.110	7.2	11.0	15.1	21.4	41.8	76.5	100.7	121.1	166.6
Pensarn_P9_58_H2	293871	378531	43.1	35.9	0.020	0.080	6.8	9.6	12.7	17.2	31.1	54.5	69.0	89.3	116.0
Pensarn_P9_59_H2	293867	378541	49.6	37.0	0.017	0.073	8.5	12.3	16.2	22.1	37.9	64.8	81.4	95.4	117.3
Pensarn_P9_61_H3	293860	378559	16.3	12.7	0.015	0.062	1.8	2.9	4.2	6.2	13.1	21.3	26.3	33.5	41.4
Pensarn_P9_62_H2	293857	378569	72.3	48.1	0.009	0.040	9.3	14.5	21.0	31.7	66.6	99.8	117.1	132.6	154.1
Pensarn_P9_63_H1	293853	378578	77.8	66.2	0.021	0.092	12.4	17.2	22.3	30.5	55.2	98.7	126.4	154.3	206.3
Pensarn_P10_64_H2	293827	378504	38.5	34.9	0.020	0.077	6.1	8.5	10.8	14.0	25.1	46.1	66.5	87.7	110.8
Pensarn_P10_65_H2	293824	378514	41.5	35.6	0.021	0.088	6.7	9.4	12.3	16.4	29.0	51.4	67.3	84.9	113.5
Pensarn_P10_66_H2	293820	378523	41.3	33.8	0.021	0.094	7.1	10.0	12.9	16.9	29.8	52.5	67.4	82.7	104.1
Pensarn_P10_68_H3	293813	378542	19.8	16.2	0.017	0.067	2.6	3.9	5.3	7.6	15.3	25.9	32.0	39.3	50.8
Pensarn_P10_69_H1	293810	378551	113.9	75.0	0.015	0.060	25.2	34.9	44.9	57.7	94.8	144.6	181.3	208.6	253.7

Table A2: Summary table of results of DGS analysis for Morfa Dinlle. Sample ID, corresponding Easting and Northing coordinates, arithmetic mean, arithmetic sorting, arithmetic skewness, arithmetic kurtosis, and D5 to D95 values.

Sample ID	Easting	Northing	Mean	Sort	Skew	Kurt	D_{5}	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_{95}
MorfaDinlle_P1_1_H2	243028	359007	52.6	40.7	0.018	0.072	9.6	14.0	18.1	23.8	40.1	64.3	83.3	104.1	137.9
MorfaDinlle_P1_2_H2	243023	359007	39.0	31.7	0.023	0.105	7.2	10.1	13.1	17.0	28.9	46.8	59.4	74.6	101.9
MorfaDinlle_P1_3_H2	243019	359006	50.7	41.9	0.018	0.063	9.4	12.7	16.1	21.1	35.5	61.8	85.6	110.7	141.6
MorfaDinlle_P1_4_H1	243013	359005	153.1	75.1	0.012	0.054	49.0	64.8	79.8	104.0	138.6	184.2	213.5	245.7	292.6
MorfaDinlle_P1_6_H1	243004	359004	108.5	80.3	0.017	0.065	21.4	28.7	36.5	48.5	83.9	141.0	177.2	206.0	257.2
MorfaDinlle_P2_8_H2	243020	359057	45.1	37.3	0.019	0.081	7.2	10.3	13.5	17.9	32.7	57.7	75.5	91.2	117.6
MorfaDinlle_P2_9_H2	243015	359056	50.9	43.2	0.016	0.058	7.1	10.4	13.8	18.5	35.8	66.2	86.8	110.9	144.9
MorfaDinlle_P2_10_H2	243010	359055	42.7	36.4	0.021	0.090	6.5	9.5	12.6	17.0	30.2	53.8	69.1	86.3	115.4
MorfaDinlle_P2_11_H1	243005	359054	84.2	49.4	0.009	0.037	20.2	26.7	33.1	44.0	74.0	112.5	130.6	148.6	178.1
MorfaDinlle_P2_12_H1	243000	359054	78.3	51.1	0.010	0.038	13.3	20.2	27.1	36.9	66.3	105.6	127.2	148.4	176.6
MorfaDinlle_P2_13_H1	242995	359053	88.1	47.9	0.011	0.044	25.0	32.6	40.5	50.3	79.7	111.1	126.6	148.2	182.2
MorfaDinlle_P2_14_H1	242990	359052	63.2	48.2	0.014	0.051	9.7	14.3	19.2	26.4	47.7	83.0	106.4	129.7	163.6
MorfaDinlle_P3_15_H2	243014	359105	45.7	38.1	0.019	0.072	7.7	10.8	14.0	18.5	32.6	56.7	75.8	95.1	125.4
MorfaDinlle_P3_16_H2	243009	359105	48.8	45.2	0.018	0.065	6.2	9.1	12.1	16.5	32.5	59.2	84.5	116.3	145.7
MorfaDinlle_P3_17_H2	243004	359104	38.7	33.3	0.024	0.113	6.4	9.0	11.7	15.5	28.2	47.6	59.7	75.4	102.2
MorfaDinlle_P3_18_H3	242999	359103	15.0	12.2	0.020	0.080	2.6	3.7	4.9	6.6	11.1	17.4	24.7	31.5	39.4
MorfaDinlle_P3_19_H3	242994	359102	20.6	15.7	0.015	0.051	3.5	5.1	6.9	9.3	15.2	26.7	36.0	43.6	51.8
MorfaDinlle_P3_21_H3	242984	359101	7.8	7.8	0.034	0.213	1.2	1.6	2.1	2.8	5.0	9.1	11.9	15.4	21.4
MorfaDinlle_P4_22_H2	243009	359147	49.6	38.6	0.018	0.071	9.3	13.0	16.6	21.8	36.4	64.0	79.4	98.8	127.5
MorfaDinlle_P4_23_H2	243004	359146	42.8	34.6	0.020	0.087	7.3	10.1	13.1	17.5	30.9	55.7	70.7	87.0	107.2
MorfaDinlle_P4_24_H2	242999	359146	37.7	34.3	0.023	0.103	5.0	7.4	9.9	13.6	25.6	47.5	60.1	76.9	104.4
MorfaDinlle_P4_26_H3	242989	359145	16.1	12.1	0.019	0.082	3.2	4.3	5.5	7.1	12.4	20.8	25.5	30.8	38.4
MorfaDinlle_P4_28_H3	242979	359144	7.5	8.3	0.034	0.192	1.0	1.4	1.8	2.4	4.4	8.2	11.5	15.5	23.0
MorfaDinlle_P5_29_H2	243006	359198	59.4	45.0	0.016	0.056	11.8	16.6	20.9	27.1	45.5	71.0	93.8	128.1	156.9
MorfaDinlle_P5_30_H2	243001	359197	42.8	34.8	0.020	0.086	7.8	10.9	13.9	18.2	31.1	52.5	67.9	86.7	109.9
MorfaDinlle_P5_31_H2	242996	359197	34.5	30.4	0.025	0.119	5.4	7.8	10.2	13.7	24.2	41.6	53.6	69.2	93.8
MorfaDinlle_P5_32_H2	242991	359197	40.9	31.2	0.021	0.100	7.7	10.9	14.0	18.3	31.2	51.3	63.5	77.5	99.8
MorfaDinlle_P5_33_H3	242985	359196	11.5	10.8	0.022	0.101	1.3	2.0	2.7	3.7	7.4	14.5	19.7	24.9	32.4
MorfaDinlle_P5_34_H3	242981	359196	19.6	13.7	0.014	0.056	3.5	5.1	6.7	8.9	15.8	26.3	31.7	36.9	45.9
MorfaDinlle_P5_35_H3	242976	359195	16.6	12.9	0.019	0.076	3.1	4.4	5.7	7.4	12.2	20.9	26.4	33.0	42.2
MorfaDinlle_P6_36_H2	242999	359246	46.3	39.6	0.022	0.088	8.4	11.8	15.0	19.4	32.3	56.4	74.9	92.1	126.3
MorfaDinlle_P6_37_H2	242993	359246	46.0	37.6	0.021	0.085	8.7	11.9	15.3	19.8	34.1	55.4	70.9	90.2	126.7
MorfaDinlle_P6_38_H2	242988	359246	39.8	36.4	0.023	0.099	6.2	8.7	11.2	14.8	26.5	50.5	65.3	77.7	111.7
MorfaDinlle_P6_39_H2	242983	359245	43.5	33.3	0.020	0.089	7.5	10.8	14.5	19.7	33.7	53.9	67.6	84.2	108.0
MorfaDinlle_P6_40_H3	242978	359245	13.9	11.1	0.020	0.090	2.0	3.1	4.1	5.7	10.5	18.1	22.6	27.0	34.8
MorfaDinlle_P6_41_H2	242974	359244	32.1	31.5	0.028	0.142	4.2	6.3	8.4	11.4	21.8	37.2	49.2	64.8	89.9
MorfaDinlle_P7_43_H2	242997	359296	47.8	39.0	0.019	0.072	8.6	12.0	15.4	20.2	34.5	59.2	77.3	96.9	131.4
MorfaDinlle_P7_44_H2	242992	359296	38.7	31.8	0.022	0.100	7.3	10.0	12.6	16.1	27.3	48.0	62.7	77.6	101.1
MorfaDinlle_P7_45_H2	242987	359295	37.0	33.8	0.022	0.097	5.6	7.9	10.2	13.6	24.3	47.2	60.6	75.8	105.2
MorfaDinlle_P7_46_H2	242982	359295	47.2	37.3	0.019	0.078	8.8	12.3	15.8	20.3	34.9	58.8	76.4	94.8	120.1
MorfaDinlle_P8_50_H2	242993	359342	46.5	35.2	0.019	0.074	9.5	13.2	16.8	21.2	35.1	57.6	71.5	89.2	121.4
MorfaDinlle_P8_51_H2	242988	359342	52.7	39.7	0.015	0.057	9.3	13.1	17.1	22.6	39.8	69.6	86.7	105.1	134.7
MorfaDinlle_P8_52_H2	242983	359342	36.8	31.4	0.025	0.120	6.3	9.0	11.9	15.8	26.5	43.9	55.3	70.9	96.8
MorfaDinlle_P8_53_H2	242978	359342	43.6	32.8	0.021	0.095	8.1	11.7	15.5	20.4	33.9	54.6	66.1	80.0	106.7
MorfaDinlle_P9_57_H2	242991	359391	49.0	38.9	0.022	0.093	9.8	13.8	17.8	22.8	37.4	57.5	73.6	95.6	128.9
MorfaDinlle_P9_58_H2	242986	359392	39.9	31.4	0.021	0.093	7.3	10.5	13.5	17.3	29.1	50.3	62.1	77.3	102.8
MorfaDinlle_P10_64_H2	242994	359441	54.2	36.6	0.016	0.066	12.4	16.9	20.9	26.8	43.3	68.9	84.0	100.3	124.5
MorfaDinlle_P10_65_H2	242989	359441	36.1	34.7	0.023	0.096	4.9	7.1	9.4	12.5	23.1	42.5	57.3	79.1	113.2
MorfaDinlle_P10_66_H2	242983	359441	30.0	26.8	0.025	0.122	4.1	6.1	8.1	11.0	20.7	36.3	46.9	61.4	82.6
MorfaDinlle_P10_67_H2	242979	359441	29.7	29.2	0.027	0.134	4.1	6.0	7.7	10.2	18.8	34.7	48.2	63.5	85.0

Table A3: Summary table of results of DGS analysis for Borth. Sample ID, corresponding Easting and Northing coordinates, arithmetic mean, arithmetic sorting, arithmetic skewness, arithmetic kurtosis, and D5 to D95 values.

Sample ID	Easting	Northing	Mean	Sort	Skew	Kurt	D_5	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_{95}
Borth_P1_1_H1	260762	291067	73.6	59.4	0.018	0.067	12.0	17.4	22.3	30.1	53.7	92.1	122.6	153.7	196.0
Borth_P1_2_H2	260752	291067	57.1	41.0	0.015	0.054	10.8	15.5	20.0	26.2	44.0	74.0	93.6	112.8	140.8
Borth_P1_3_H2	260742	291067	48.5	37.9	0.017	0.071	7.2	10.9	14.2	19.6	36.3	64.2	78.2	93.6	124.3
Borth_P1_4_H2	260732	291066	52.6	38.0	0.016	0.065	8.8	13.6	18.3	23.9	41.3	68.4	84.9	102.4	123.2
Borth_P2_8_H1	260765	290997	87.4	63.0	0.020	0.084	19.3	25.9	32.2	42.0	70.4	105.0	132.0	162.8	210.0
Borth_P2_9_H2	260755	290997	44.0	34.7	0.018	0.079	7.6	10.6	13.4	17.6	32.7	57.2	71.4	87.6	110.5
Borth_P2_10_H3	260745	290997	16.6	12.4	0.019	0.075	3.6	4.8	6.0	7.5	12.7	20.5	26.0	32.2	41.9
Borth_P2_11_H2	260735	290996	41.9	33.4	0.019	0.089	6.2	9.4	12.4	16.6	31.2	54.9	69.5	82.3	101.6
Borth_P3_15_H1	260767	290927	72.9	57.0	0.022	0.102	13.6	19.3	24.8	32.4	55.4	89.5	109.9	136.1	181.8
Borth_P3_16_H2	260757	290927	56.2	42.7	0.016	0.061	10.3	14.4	18.5	24.5	42.1	73.9	91.0	110.6	143.6
Borth_P3_17_H2	260748	290927	46.9	38.3	0.017	0.070	7.3	10.3	13.4	18.2	33.1	63.5	81.0	95.4	119.1
Borth_P4_22_H1	260770	290857	76.0	59.9	0.021	0.095	12.7	18.2	24.0	32.6	57.4	96.8	121.5	146.2	189.7
Borth_P4_23_H2	260760	290857	55.6	42.2	0.017	0.064	10.8	15.0	18.7	24.2	41.0	74.4	92.1	109.2	135.0
Borth_P4_24_H2	260751	290865	46.7	41.6	0.018	0.066	6.1	9.0	12.1	16.5	31.0	59.8	83.3	102.8	131.1
Borth_P5_29_H2	260772	290788	49.4	39.7	0.019	0.076	9.0	12.8	16.8	22.1	35.6	60.6	78.5	97.8	131.5
Borth_P5_30_H2	260762	290787	42.6	35.8	0.022	0.092	7.9	11.1	14.2	18.1	30.0	51.4	69.1	85.1	113.8
Borth_P5_31_H2	260752	290787	51.0	41.4	0.017	0.066	8.3	12.0	16.0	21.2	36.5	65.2	84.6	104.9	137.4
Borth_P6_37_H2	260775	290717	63.7	40.2	0.013	0.050	14.4	20.6	26.4	33.7	52.7	80.6	98.5	119.9	144.3
Borth_P6_38_H2	260764	290718	54.1	39.9	0.014	0.054	9.0	13.2	17.7	24.0	41.5	70.4	93.4	109.4	130.7
Borth_P6_39_H2	260754	290717	48.1	36.9	0.014	0.058	5.1	8.8	12.9	18.6	38.1	65.7	80.4	95.5	115.6
Borth_P7_43_H1	260777	290648	109.3	73.5	0.016	0.062	28.0	36.2	44.2	55.1	85.1	139.3	171.0	204.1	253.9
Borth_P7_44_H2	260767	290647	64.3	44.8	0.014	0.049	14.4	19.7	24.5	31.2	49.3	81.6	107.2	126.6	157.9
Borth_P7_45_H2	260757	290647	56.8	46.4	0.013	0.044	6.6	9.8	13.5	19.7	41.2	79.3	105.8	125.6	146.3
Borth_P8_50_H1	260782	290574	79.5	63.7	0.023	0.098	16.3	22.5	28.7	37.4	59.7	89.8	117.7	160.0	209.3
Borth_P8_51_H2	260772	290573	55.1	38.0	0.017	0.070	12.2	17.3	21.3	26.8	45.0	69.1	83.2	101.0	132.9
Borth_P8_52_H2	260762	290572	49.8	37.7	0.017	0.068	8.8	12.3	16.0	21.3	38.3	64.6	79.5	96.4	124.7
Borth_P8_53_H2	260752	290571	62.7	47.7	0.012	0.045	9.1	13.7	18.4	24.7	46.8	89.4	108.2	126.3	153.9
Borth_P9_56_H2	260782	290508	33.8	32.9	0.025	0.116	3.8	5.9	8.1	11.5	21.9	40.0	55.9	75.6	98.6
Borth_P9_57_H1	260771	290508	79.4	60.7	0.024	0.105	20.9	26.3	31.6	38.7	59.3	92.6	116.3	145.6	204.5
Borth_P9_58_H2	260761	290508	60.8	40.5	0.015	0.066	13.1	17.7	22.4	29.7	50.5	80.8	96.1	108.4	128.2
Borth_P9_59_H2	260751	290507	46.1	38.0	0.021	0.084	8.4	11.7	14.9	19.4	33.8	56.5	72.3	93.1	122.7
Borth_P9_60_H2	260741	290507	44.1	36.8	0.020	0.080	6.9	9.9	13.0	17.2	32.3	56.1	70.3	85.5	121.8
Borth_P10_65_H1	260783	290438	99.2	75.0	0.019	0.071	21.5	29.1	36.3	45.9	74.8	121.8	153.8	193.8	256.6
Borth_P10_66_H1	260773	290438	83.4	63.9	0.021	0.093	15.3	21.6	27.7	36.7	65.0	105.4	132.9	157.4	198.6
Borth_P10_67_H2	260764	290437	48.0	34.8	0.017	0.073	9.7	13.4	17.3	22.4	36.5	61.1	77.5	93.8	112.8
Borth_P10_68_H2	260754	290437	46.4	41.6	0.019	0.070	6.5	9.4	12.3	16.5	31.7	58.9	76.4	97.8	139.6

Table A4: Summary table of results of DGS analysis for Amroth. Sample ID, corresponding Easting and Northing coordinates, arithmetic mean, arithmetic sorting, arithmetic skewness, arithmetic kurtosis, and D5 to D95 values.

Sample ID	Easting	Northing	Mean	Sort	Skew	Kurt	D_5	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_{95}
Amroth_P1_1_H1	216282	207002	83.1	57.4	0.019	0.090	18.4	25.9	32.4	41.6	66.7	102.7	124.6	147.5	193.6
Amroth_P1_2_H1	216285	206993	81.2	58.6	0.023	0.111	18.7	25.6	31.7	40.0	63.9	99.7	121.8	145.2	189.1
Amroth_P1_3_H2	216289	206984	51.3	37.0	0.021	0.089	12.7	17.0	20.6	25.4	41.3	61.4	73.3	91.2	127.8
Amroth_P1_4_H1	216293	206974	173.1	91.7	0.006	0.030	44.2	59.1	75.1	95.7	160.5	231.9	266.6	298.7	338.0
Amroth_P2_8_H1	216399	207040	85.9	61.8	0.020	0.092	17.2	24.8	31.8	41.4	68.7	106.4	131.1	159.8	199.1
Amroth_P2_9_H1	216402	207030	80.4	58.6	0.024	0.116	17.5	25.0	31.7	40.8	64.0	95.4	119.3	145.0	185.2
Amroth_P2_10_H2	216406	207021	54.4	39.3	0.018	0.071	11.8	16.5	21.1	27.2	43.4	64.0	82.8	105.2	136.9
Amroth_P3_15_H1	216486	207061	82.5	60.1	0.021	0.097	21.7	27.2	32.7	39.9	60.4	102.4	129.6	159.5	194.3
Amroth_P3_16_H1	216490	207051	95.0	72.9	0.018	0.067	19.7	26.5	33.3	42.3	68.6	121.4	155.6	191.4	243.5
Amroth_P3_17_H1	216492	207043	98.8	57.9	0.007	0.030	22.2	30.4	38.3	50.3	89.4	130.9	158.2	180.6	211.6
Amroth_P4_22_H2	216857	207151	52.5	38.7	0.017	0.065	11.1	15.1	18.9	23.8	38.9	69.4	88.0	103.5	125.3
Amroth_P4_23_H2	216860	207142	55.0	39.7	0.017	0.064	13.0	17.4	21.3	26.5	42.6	66.4	85.6	109.1	139.7
Amroth_P4_24_H1	216864	207132	154.9	98.6	0.010	0.038	32.9	43.4	55.6	75.3	132.0	206.4	244.8	286.9	346.1
Amroth_P5_29_H2	216908	207157	46.1	35.4	0.017	0.068	9.3	12.4	15.5	20.0	33.3	58.8	76.5	94.1	118.3
Amroth_P5_30_H2	216912	207148	76.0	51.3	0.012	0.043	13.8	20.0	27.0	36.8	63.6	99.9	121.4	147.4	181.4
Amroth_P5_31_H1	216917	207139	99.4	49.3	0.006	0.030	28.7	38.4	48.3	60.4	90.6	131.6	150.3	165.1	184.5
Amroth_P6_36_H2	216958	207166	49.4	36.7	0.019	0.080	10.5	14.1	17.6	22.7	37.7	61.9	79.4	96.0	119.1
Amroth_P6_37_H2	216962	207157	65.1	43.1	0.014	0.051	14.9	20.3	25.4	32.3	53.2	82.7	103.0	124.3	152.5
Amroth_P6_38_H1	216967	207149	160.7	94.6	0.010	0.037	39.9	52.9	64.7	85.4	141.0	210.0	250.7	289.7	348.9
Amroth_P7_43_H2	217208	207213	39.9	31.6	0.021	0.092	8.7	11.7	14.3	17.7	28.8	47.5	63.3	81.3	103.7
Amroth_P7_44_H2	217210	207203	47.6	34.8	0.020	0.085	10.8	14.9	18.6	23.5	36.0	58.6	73.0	90.5	117.0
Amroth_P7_45_H2	217213	207194	49.7	39.1	0.020	0.079	9.5	13.2	16.8	21.9	37.3	61.7	77.2	98.0	127.3
Amroth_P8_50_H2	217277	207239	59.2	40.6	0.015	0.057	14.4	19.0	23.1	28.7	47.0	73.7	93.7	114.9	142.7
Amroth_P8_51_H2	217279	207228	57.8	39.4	0.016	0.061	14.3	19.3	24.0	29.8	44.9	70.7	91.6	114.6	137.8
Amroth_P8_52_H1	217282	207219	76.4	42.6	0.011	0.043	23.7	29.8	35.4	42.5	65.2	98.7	116.4	133.7	156.4
Amroth_P8_53_H1	217285	207210	132.5	77.8	0.011	0.047	36.6	46.3	56.2	69.0	113.1	175.6	202.4	231.3	272.7
Amroth_P9_57_H1	217340	207247	90.3	61.5	0.020	0.087	25.1	31.4	37.6	45.3	71.4	111.0	135.8	163.4	212.8
Amroth_P9_58_H1	217342	207237	90.2	60.7	0.021	0.098	22.9	30.6	37.1	47.0	73.1	111.4	134.7	161.2	198.9
Amroth_P9_59_H2	217344	207228	61.7	43.5	0.016	0.060	13.9	19.3	24.2	30.7	47.5	76.4	97.6	121.8	151.0
Amroth_P9_60_H1	217347	207218	133.3	77.5	0.011	0.044	34.0	47.4	59.2	73.3	115.6	170.5	197.8	238.1	289.9

Table A5: Summary table of results of DGS analysis for Leys. Sample ID, corresponding Easting and Northing coordinates, arithmetic mean, arithmetic sorting, arithmetic skewness, arithmetic kurtosis, and D5 to D95 values.

Sample ID	Easting	Northing	Mean	Sort	Skew	Kurt	D_{5}	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_{95}
Leys_P1_1_H1	302276	165745	95.1	65.7	0.017	0.065	24.3	31.8	38.9	47.6	69.8	122.9	152.3	180.2	223.8
Leys_P1_1_H2	302266	165741	70.6	41.8	0.013	0.049	20.1	27.1	32.6	40.1	58.4	87.8	110.5	129.4	153.3
Leys_P1_3_H1	302257	165738	107.1	74.0	0.013	0.051	21.6	30.1	38.2	48.8	81.8	151.1	179.7	202.1	239.5
Leys_P1_6_H2	302228	165728	55.9	39.2	0.014	0.057	8.6	13.5	18.9	25.9	46.7	72.5	91.5	106.3	127.8
Leys_P1_7_H2	302219	165724	56.0	40.3	0.014	0.055	7.9	12.5	17.6	24.6	46.6	71.9	88.7	110.2	135.3
Leys_P2_8_H1	302300	165680	126.9	71.7	0.011	0.048	35.4	46.3	55.8	69.4	110.8	164.7	192.2	217.2	254.5
Leys_P3_15_H1	302338	165671	132.3	79.3	0.014	0.056	33.2	45.8	58.4	74.1	116.0	164.4	189.4	229.3	294.9
Leys_P3_16_H2	302340	165661	72.1	45.0	0.010	0.043	14.5	21.1	27.0	34.9	62.6	97.8	114.5	128.3	154.9
Leys_P3_18_H1	302344	165641	129.6	80.0	0.013	0.052	29.5	42.6	54.6	68.8	108.8	169.8	200.0	231.9	278.4
Leys_P3_19_H1	302345	165631	144.4	91.7	0.011	0.042	30.8	44.5	58.5	75.6	120.5	189.6	230.8	267.5	326.2
Leys_P3_20_H2	302347	165622	80.7	49.4	0.010	0.040	16.5	25.3	32.7	42.2	69.2	106.8	125.8	147.3	179.7
Leys_P3_21_H2	302349	165612	77.9	47.7	0.011	0.043	14.8	22.3	30.3	42.5	68.3	100.9	119.7	139.8	170.2
Leys_P4_22_H2	302408	165681	61.5	41.8	0.015	0.058	13.0	18.4	23.5	30.9	50.4	77.5	96.7	114.5	145.5
Leys_P4_23_H1	302410	165671	119.1	74.9	0.016	0.067	30.4	41.2	51.1	64.5	101.2	144.9	174.9	213.3	262.6
Leys_P4_24_H1	302412	165661	163.5	83.7	0.008	0.037	48.9	66.2	80.7	96.0	146.4	215.6	244.9	271.7	311.1
Leys_P4_25_H1	302413	165651	143.1	85.4	0.012	0.048	34.4	49.1	64.5	82.7	120.4	182.1	216.7	256.6	308.1
Leys_P4_26_H1	302415	165641	134.2	79.6	0.008	0.031	32.4	44.1	54.4	71.1	113.9	181.7	217.5	250.4	289.3
Leys_P4_27_H1	302417	165632	103.8	55.6	0.006	0.031	25.0	35.3	45.5	59.5	92.8	139.9	159.2	177.0	201.9
Leys_P5_29_H1	302478	165690	122.9	79.0	0.013	0.046	31.3	41.0	50.2	63.7	97.5	158.7	196.0	235.5	285.4
Leys_P5_30_H2	302480	165680	73.6	48.8	0.012	0.043	15.8	22.0	28.4	36.7	59.9	95.4	121.6	144.6	171.0
Leys_P5_31_H1	302482	165671	84.5	48.3	0.009	0.039	18.8	26.6	34.9	46.0	77.4	110.0	129.4	146.8	173.5
Leys_P5_32_H1	302484	165661	137.2	79.3	0.011	0.046	33.3	46.1	58.5	74.6	122.2	178.2	210.6	239.7	278.8
Leys_P5_34_H1	302487	165641	104.7	55.5	0.006	0.030	25.7	36.6	47.0	60.5	94.9	138.7	161.1	181.8	206.2
Leys_P5_35_H2	302489	165631	93.5	47.4	0.007	0.041	22.1	33.7	43.7	56.8	91.0	120.4	132.6	144.6	168.6
Leys_P6_36_H1	302542	165705	143.4	87.5	0.011	0.042	37.1	48.3	61.2	76.7	117.8	185.2	226.3	268.3	312.9
Leys_P6_37_H1	302544	165695	93.7	70.0	0.020	0.082	20.3	27.7	35.3	45.2	70.8	114.9	147.0	180.0	228.3
Leys_P6_38_H1	302547	165685	122.7	82.1	0.012	0.047	24.4	34.7	45.8	59.9	99.2	164.3	199.0	230.9	282.2
Leys_P6_39_H1	302549	165675	101.2	47.1	0.006	0.033	33.8	43.6	52.1	63.7	94.0	131.1	146.1	160.7	182.2
Leys_P6_40_H1	302553	165666	112.3	73.7	0.018	0.070	29.8	41.5	50.4	60.7	91.6	135.5	161.7	200.6	268.7
Leys_P6_41_H1	302555	165656	124.4	76.8	0.017	0.067	35.5	45.7	55.8	70.0	105.5	151.3	177.5	214.6	281.2
Leys_P6_42_H1	302558	165647	99.4	48.1	0.008	0.037	31.1	41.2	51.0	63.1	91.2	125.9	144.8	162.5	187.8
Leys_P7_43_H2	302611	165722	63.9	38.9	0.013	0.053	14.9	21.3	27.2	34.3	55.8	82.6	95.5	109.4	138.4
Leys_P7_44_H1	302611	165717	86.3	64.2	0.022	0.100	19.9	26.4	32.7	41.0	66.5	107.3	132.2	157.7	207.4
Leys_P7_45_H1	302615	165707	129.6	82.3	0.015	0.058	29.8	42.9	53.5	70.2	112.3	157.1	191.9	228.6	303.1
Leys_P7_48_H1	302623	165679	102.6	66.2	0.018	0.080	26.6	35.1	43.8	55.8	84.9	125.5	150.5	180.9	233.2
Leys_P7_49_H1	302626	165670	103.7	69.3	0.018	0.072	23.3	33.1	43.0	55.3	85.2	126.5	155.3	183.5	245.1
Leys_P7_49.5_H1	302609	165726	80.2	50.1	0.014	0.050	21.5	28.4	34.9	43.7	66.4	99.0	121.4	149.0	186.2
Leys_P8_50_H1	302674	165752	82.9	48.2	0.011	0.041	22.7	30.3	37.1	46.7	70.4	104.6	130.0	152.0	177.8
Leys_P8_51_H2	302677	165743	60.8	42.7	0.017	0.065	14.7	19.7	24.0	29.9	46.6	77.5	94.1	113.2	146.4
Leys_P8_53_H2	302680	165733	63.2	40.8	0.013	0.050	14.9	20.7	25.9	32.5	51.3	80.8	99.2	118.9	145.9
Leys_P8_54_H2	302683	165724	62.1	40.3	0.016	0.064	15.4	21.3	26.9	33.1	50.9	76.5	95.6	115.3	138.6
Leys_P9_57_H1	302807	165784	88.9	50.8	0.009	0.037	21.7	30.3	38.5	49.7	77.6	116.0	136.4	157.6	188.5
Leys_P9_58_H1	302806	165774	77.2	47.3	0.013	0.048	18.9	25.9	32.8	42.0	65.1	97.5	119.7	141.3	172.2
Leys_P9_59_H2	302805	165764	49.9	36.4	0.019	0.077	11.6	15.6	19.3	23.9	38.4	60.4	77.8	97.0	122.9
Leys_P9_60_H2	302803	165754	71.0	44.1	0.011	0.042	17.5	23.3	28.9	37.0	59.4	88.9	117.0	136.7	156.0
Leys_P9_61_H1	302802	165745	137.5	77.9	0.014	0.054	44.6	56.5	67.2	78.0	116.7	177.7	206.0	231.1	283.0

Appendix B: Summary table of sand and gravel quarries:

Table B1: Summary table of the sand and gravel quarries located in Wales according to the BGS Directory of Mines and Quarries 2020. Easting and Northing coordinates have been provided, as well as operating company name, contact number, status, size of material available. Location of a limestone quarry with suitable sizes of material for Leys has also been included.

Quarry name	Easting	Northing	Operator	Contact	Status	Size (mm)	Description
Llwynjack	275400	233100	CJ Lewis	01550 720247	Active	Unknown	No response
Cware Crug Yr Eryr	241945	250495	Cware Crug Yr Eryr Cyf	01545 590578	Active	2 - 150	Depleted resources
Pant	265875	256570	Teifi Sand & Gravel	Unknown	Unknown	Unknown	Unknown
Penparc	220130	248310	Cardigan Sand and Gravel Co. Ltd.	01239 612560	Active	2 – 60 (4 sizes)	Predominantly sand
Fron Haul	315721	370551	Breedon Southern	01352 720343	Closed	Unknown	Closed
Maes Mynan	312414	371970	Breedon Southern	Unknown	Closed	Unknown	Closed
Cefn Graianog	245895	349725	TG Aggregates (Tudor Griffiths Group)	01691 626262	Active	2 - 300	Quartzite rounded
Llecheiddior-uchaf Gravel Pit	247580	344560	Cambrian Services Ltd.	Unknown	Closed	Unknown	Closed
Penygroes Pit	246370	352985	Tudor Griffiths Group	Unknown	Closed	Unknown	Closed
Bedwin Sands	347500	183000	Seevern Sands Ltd.	01633 266689	Active	2 – 40	Predominantly sand
Cware Pantgwyn	212435	242170	Cware Pantgwyn Quarry Ltd.	01239 881246	Active	70 – 130 (byproduct)	Predominantly sand
Cware Trefigin	213670	243335	Trefigin Quarries Ltd.	01239 881282	Active	2 – 40	Predominantly sand
Ballswood	334770	356435	DP Williams Sand & Gravel	01978 852767	Active	2 – 20	Predominantly sand
Borras	336611	352625	Breedon Southern	01978 788880	Active	2 – 20	Predominantly sand
Taff Wells	312074	182189	Tarmac – Taff Wells Quarry	01443 233133	Active	40 – 80 and 100 – 150	Limestone

Appendix C: Data Archive Appendix

.Digital grain sizing data is available as an excel file and digital images used in the grain sizing are also available.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue NRW Data Discovery | home (naturalresources.wales) (English Version) and Darganfod Data CNC | home (naturalresources.wales) (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record no NRW_DS161276

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